ADDIS ABABA SCIENCE AND TECHNOLOGY UNIVERSITY

College of Architecture and Civil Engineering
Department of Civil Engineering

Water Supply Coverage and Water Losses in the Distribution System of Akaki Kality Sub City, Ethiopia

By Nega Abera

A Thesis Submitted to the College of Architecture and Civil Engineering in Addis Ababa Science and Technology University for the :- in partial fulfillment of the requirements for the Degree of Master of Science in Civil Engineering (Hydraulic Engineering) .

September 18, 2018
Addis Ababa, Ethiopia

Declaration

I, the undersigned person, declare that thesis is my original work and that all sources of materials used for this thesis have been dully acknowledged.

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Date of Submission	September18, 2018

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Advisor: - Brook Abate (PhD)	__________	____________

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ABSTRACT

Reduction of non-revenue water is one of the major challenges facing many water utilities in Addis Ababa Water and Sewerage Authority in general and Akaki branch in particular. So, the study focuses on the assessment of water loss in water supply networks in Akaki Kality sub city using Aqua Lite Water balance software and water CAD software. Aqua Lite water software was used to analyze water loss components and calculate unavoidable annual real losses as well as the use of infrastructure leakage index as a key for the efficiency of the system was evaluated using performance indicators .Water CADV8i software was also used to simulate the distribution water supply network. Five pilot District Metered Areas were delineated for different sites and identifying the possible causes of water losses with different possible measurement which Addis Ababa Water and Sewerage Authority must take. Focus group discussions were made with local experts' to support the quantitative analysis. The focus of this study is to evaluate the sub city distribution coverage of the water supply and evaluating the total water loss. Customer meter readings were used to evaluate the existing water coverage and total water loss. From the result of the analysis, it was obtained that the total water loss in Akaki Kality water supply system is high reaches up to 39.87% of the system input volume and about 31.43% of the total system loss is real losses and 8.44% apparent losses. Besides, the average daily per capita water consumption of the sub city is 35 liter/person/day. As it is difficult to directly characterize the causes of losses from a total water loss, in this study it is attempted to identify the possible causes of the loss with possible solution. Water Cad software run was also performed for 12 different sample sites to analyze the system mode and comparing the representative sample of distribution pressure field test with the model simulated values which shows a reasonable and small difference in calibrate the model.

Key words: *Water coverage, water loss, non-revenue water, District meter area, Aqua Lite software, water CAD, and Akaki Kality.*

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LIST OF ABBREVIATIONS

AAWSA	Addis Ababa Water and Sewerage Authority
ADD	Average Daily Demand
AWWA	American Water Work Associations
DMA	District Metering Area
EPS	Extended Period Simulation
GIS	Geographical Information System
GW	Ground Water
ILI	Infrastructure Leakage Index
IWA	International Water Association
MDD	Maximum Daily Demand
MNF	Minimum Night Flow
NGO	Non-Governmental Organization
NRW	Non-Revenue Water
PHD	Peak Hourly Demand
RL	Real Loss
UARL	Unavoidable Annual Real Loss
UFW	Unaccounted for Water
USEPA	United State Environmental Protection Agency
WHO	World Health Organization

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

INTRODUCTION

1.1 Back ground of the Study

Water is the primary need to sustain life; every citizen in the country has the right to have access to potable water. Provision of safe and adequate water supply services is necessary component for sustainable development. Problems in providing satisfactory water supply to the rapidly growing population especially that of the developing countries is increasing from time to time. Water supply systems in urban areas are often unable to meet existing demands and are not available to everyone rather some consumers take disproportionate amounts of water and the poor is the first victim to the problem. The provision of adequate and reliable water supply in developing countries is becoming a challenge for most water utilities especially public service providers. Water demand has been increasing drastically in these countries due to many factors including population growth as a result of rural to urban migration. As a consequence, in many countries public service utilities have failed to provide consumers with adequate water supply and sanitation services. Apart from service coverage, there are other problems that affect public service providers such as high unaccounted for water (UfW) and financial problems due to a combination of low tariff, poor services, poor consumer records and inefficient billing practices (Kimey, 2008).

The provision of adequate supplies potable water for use in urban areas in developing countries is crucial for the well-being of the people. The demand for such supplies in the developing countries has been on the increase over time as a result of rising standards of living that occur with economic progress and population increase resulting from natural growth, and rural urban migration and rising per capital income.

Access to safe and adequate water supply is a universally recognized human right, which has special significance to the survival of humanity. Adequate water supply may be defined as having reasonable access to safe water supply, performance of water utilities can be assessed by many factors including accessibility and reliability of water supply, affordability of services, and customer satisfaction. In many developing countries, however, the public service providers have failed to provide consumers with adequate water supply and sanitation services. The existing problems of inadequate service provision is exacerbated by the fact that population growth and mounting pressure of increasing urbanization have offset much of the gains in service coverage Service coverage can be one of the indicators of accessibility of water supply that can have an effect on the performance of water utilities. Apart from serving coverage there are other problems that affect the performance of the public water utilities. Moreover, the public utilities often face financial challenges due to a combination of low tariffs, poor services, poor consumer records and inefficient billing and collection practices (WHO, 2011).

A well performing urban water supply system should provide water supply for human being and livestock consumption, for industrial and other uses in terms of coverage, quantity, reliability and acceptable quality taking the existing and future realities of the city in to consideration.

According to the millennium goal targets, the African urban areas will be accessed for improved water within 15 years from the years 2000.On the other hand, in African largest cities, only 43% inhabitants have house connection water supply services (Welday, 2005). The main problem that developing countries are faced to provide access to safe water for their citizens is shortage of resources. For this reason, many developing cities are faced great difficulty to expand the service and rehabilitating the existing aged pipes. Generally, tariffs in developing countries are set well below the level needed to cover even operation and maintenance costs. Research has shown that low, tariffs are set largely for political, rather practical, purposes. Limited institutional capacity is also one of the bottlenecks that hinder cities of developing countries for managing the infrastructure asset in general and water supply in practice. Besides, to low coverage, water loss (physical loss) in urban water supply is accounted to more than 50% of the supplies that mainly arise from leakage of pipes, joints and valves, over flowing service reservoirs, wastage of water thought illegal connection and unmetered house connections.

Although leakage is one of the major causes for loss of water in a network distribution system, the loss of water through illegal connections and non- functioning meters is also contributing a lot that needs a proper management and monitoring system. While developed cities have started using on-line continuous and monitoring service, the developing cities have great difficulties even to collect information on their previously performed operation and maintenance activities that could help them developing a strategy for the future. Many developed countries use water audit procedures to determine the efficiency of the system and to identify the location and magnitude of water losses (Welday, 2005).There is also a need for some type of database or information system such as GIS to enable analysis of flows in the networks and provide early warning or indication of leakage. At present, although some cities in developing countries are introduced GIS based information system, many countries are still applying conventional methods for collecting, storing, processing and retrieval of information system, but the good news is that GIS have the ability to use previously collected and stored digital data makes introducing GIS easy and not costly. The alternate emptying and refilling of water pipe lines makes it problematic to apply standard Water CAD based hydraulic models because of low pressures and pipes without water. Water CAD was adjusted to allow for modeling pressure dependent demands, for dealing with low pressure and "dry pipe" situations. A configurable tool was developed for incorporating roof tanks into the water supply analysis and for better formulation and schematization of the system hydraulics. Water CAD is an open-structured, public domain Hydraulic and water quality model developed by USEPA and is used worldwide.

1.2 Statement of the Problem

Presently Addis Ababa city, particularly Akaki Kality sub city faces presently a serious deficit in the water supply due to increased population and expanded economic actually in and around the subsystems and also the sub city have not enough sources of water supply. The water supply sources for the Akaki Kality sub city are Akaki well fields, springs and wells located in various part of the area.

There are instants in which water shortage is accelerated by undesirable pressure within distribution system. Depending on the context of the existing system both or one of the factors may be found as a root cause for the shortfall between demand and supply. High leakage and pipe failure (due unmaintained maximum pressure) as well as provision of insufficient supply (due to unmaintained minimum pressure) are situations which propagate water shortage within distribution system.

Although the total loss of water can easily be estimated by comparing billing on water consumption and the total water produced and distributed to the network system, identifying the causes of the water loss and their spatial distribution is the challenge of many cities including Addis Ababa. For this reason many water companies that Addis Ababa water authority is among them are forced to consider the total loss as being caused by the physical loss like leakage, but in reality the causes for water loss include others such as illegal connection, non-functioning of water meters, etc.

Thus, the Addis Ababa Water and Sewerage Authority has great difficulty to identify where and how much water is lost and what are the main causes for the loss of water that this research is going to focus.

1.3 Objectives

1.3.1 General Objective

The general objective of a study is to assess water supply coverage and water losses in distribution system in Akaki Kality, Addis Ababa

1.3.2 Specific Objectives

The specific objectives of a study are:-

- To evaluate the existing water supply coverage and distribution system in Akaki Kality sub city.
- To estimate demand and project it for the next 20 years
- To study the hydraulic performance of the distribution network of Akaki sub city using Water- Cad software
- To explore the possible causes of water losses and possible solution
- To assess District Meter Area in Non-Revenue Water reduction and control.

1.4 Research Questions

The general and specific objectives of the study would be achieved by way of seeking answers to the following questions:-

1. How much water is produced and distributed to the network system?
2. How much water do domestic consumers consume?

3. What are the possible causes of water losses in Akaki water distribution system?
4. What are the possible solutions to reduce the loss?
5. How DMA can reduce and control NRW?
6. Is the distribution system hydraulically efficient?

1.5 Significance of the study

The significance of this research is to assess the existing water supply coverage and water losses in distribution system and gather information in order to provide a starting point for water supply coverage and determine the leakage in the system and identified some of the present problems. Based on findings, better system management was proposed. Actions that can be taken to reduce water losses are also identified in this paper.

The paper will be important for AAWSA as well as Non-governmental organizations (NGOs) which have interest with financial and technical support in the area can use the research outcomes as reference for their objective.

1.6 The Thesis Content

This thesis comprises five chapters, which are organized as follows.

- ✓ Chapter one: Contains general background, the problem statement, the research objective, research question, significance of the research.
- ✓ Chapter two: Discussion literature related to water loss and leakage
- ✓ Chapter three: Discussion about the methodology the data collection and preparation
- ✓ Chapter four: Results and discussion
- ✓ Chapter five: Conclusion and recommendation.

CHAPTER TWO

LITERATUREREVIEW

2.1 Introduction

Problems in providing satisfactory water supply to the rapidly growing population especially that of the developing countries is increasing from time to time. Water supply system in urban areas are often unable to meet existing demands and are not available to everyone rather some consumers take disproportionate amounts of water and the poor is the first victim develop and expand water supply projects and one of the difficulties among two others is managing and reducing losses of water at all levels of a distribution system. As a result of the overall shortage of water many cities are faced a problem in distributing the available water impartially among the residents. As this research deals with over all coverage of water supply and water losses in distribution systems, issues related to water loss and leakage like identifying and reducing was reviewed in this chapter. Leakage can be defined as unintentional or accidental loss of water from the pipe distribution network (Melaku , 2015). Leaking pipes are a major concern for water utilities around the globe as they constitute a major portion of water losses. One of the primary reasons for leakage in pipes is aged and deteriorated networks. Leakage rates are also related to length of pipes and number of connections. Improper connections can sometimes result in continuous escape of water from the distribution pipes.

2.1 Project History of Addis Ababa Water Supply Network

In 1991, Messrs. Seureca of France prepared Feasibility Study and Preliminary Design, indicating additional sources of water, both surface and groundwater, to meet the needs of the Addis Ababa Metropolitan Area until the year 2020. Dams at Sibilu and Gerbi were recommended (Tahal, 2013).

In 1994, AAWSA initiated a follow up study meant to continue the source investigation and prepare detailed design and tender documents for project implementation. The latter project started in May 1995 and was entrusted to a joint venture of Messrs, Associated Engineers and HBT AGRA both of Canada (Tahal, 2013).These consultants prepared studies and design mainly on surface water resources recommended by the earlier feasibility study, i.e., Gerbi and Sibilu dams, about 30 km north of Addis Ababa on the other side of the Entoto Hills, and on groundwater supply in the southern part of the town from the Akaki aquifer.

2.2 Urban Water Demand and Coverage

2.2.1 Urban Water Demand

Water demand is defined as the volume of water requested by users to satisfy their needs. In a simplified way it is often considered equal to water consumption, although conceptually the two terms do not have the same meaning (Wallingford., 2003). In most developing countries, that theoretical water demand considerably exceeds the actual consumptive water use. Urban water demand is classified in to different category that domestic water demands that included in-house-use and out-of -house-use is among the others. In-house-use includes demands for cooking sanitation, house cleaning, laundry and car washing while out-of-house-use includes like garden watering, swimming pools, public stand pipes for public uses and fountains,etc.

Urban water demand is usually quoted in terms of liter per capital per day (1/capita/day).Despite the variation in residential indoor water use from household to household, a typical pattern (referred to as the water use profile) can be developed to provide a reasonable representation of indoor water use, based on the different indoor water use components (kitchen, bathroom, laundry, and toilet) and household occupancy (Kanakoudis et al., 2011). In many African cities urban water demands are often homogeneous owing to a range of levels of services occurring within the same urban area. Levels of service can vary from household connections to standpipes or to no service at all (Welday, 2005).

2.2.2 Urban Water Coverage

Water supply coverage provides a picture of the water supply situation of one specific country or city and helps to compare one country with others and the inter and intra city distribution with in specific country. The percentages of population with or without piped water connection are a relevant indictor to compare the coverage of water supply in urban areas. Although the water supply coverage is better in urban areas while compared with the rural, the actual water supply coverage in cities of developing countries in general and African cities in particular is very low while compared to the demand. According to the Global Water Supply and Sanitation assessment 2000 Report, the African capital cities are having 43% house connection or yard tap,21% served by public tap while 31% of the populations are un-served (WHO, 2000). A household is considered to have access to improved drinking water if it has sufficient amount of water (20 liters/person/day) for family use, at an affordable price (less than 10% of the total household income), available to household members without being subject to extreme effort (less than one hour) a day for the minimum sufficient quantity), especially to women and children) (UN Habital, 2003).

2.2.3 Water demand and Consumption

One of the difficulties faced by the water authority is determining the accurate water demand of the sub city as the consumption during the past years that should have been used as a base is far below the actual demand due to the shortage of water. Consumption of water for the sub city is therefore estimated based on the amount supplied rather than the actual demand. For these reason estimate of the existing water supply of sub city is by analysing of the customer billing data of the authority. The current situation as summarized by the water authority is as shown below (AAWSA, 2006)

People having in-house services that are estimated about 4% of the total population use water on average between 80 and 100 liters per capital per day, while the remaining populations with access to safe drinking water (94%) are served by yard connection and use 15 and 30 liters per capital per day.

Non domestic uses excluding industrial and industries water use are about 25 liters per capital per day and 7 liters per capital per day respectively. From the water used by industries about 40% is provided by the water authority while the remaining amount is produced by the industries themselves from deep wells (SEURECA, 2007).

2.2.4 Water Demand Management

Water demand is defined as the volume of water requested by users to satisfy their needs. In a simplified way it is often considered equal to water consumption, although conceptually the two terms do not have the same meaning (Wallingford., 2003). In most developing countries, the theoretical water demand considerably exceeds the actual consumptive water use. Water demand management refers to any socially beneficial action that reduces average or peak water withdrawals or consumption form either surface or ground water, consistent with the protection or enhancement of water quality (Thomas , 2003).Water demand management is the adaptation and implementation of a strategy by an institution to influence the water demand and usage in order to meet any of the following objectives: economic efficiency, social development, social equity (Mckenzie, 2013).

Urban water demand is classified in to different category that domestic water demands that included in-house-use and out-of -house-use is among the others. In-house-use includes demands for cooking sanitation, house cleaning, laundry and car washing while out-of-house-use includes like garden watering, swimming pools, public stand pipes for public uses and fountains, etc.

2.3 Water loss and leakage

The term "water loss" is generally adopted to indicate the difference between the overall amount of water supplied in the network and the sum of the water volumes corresponding to the customer consumption recorded by the flow-meters (Lambert et al., 2009). The first and foremost cause of water loss is leakage. Water put to inappropriate or excessive uses may also be considered as loss. Water that is unaccounted for because of measurement errors, including inaccurate meters, forgotten users, and unmeasured uses, are also some of the causes for evaluating the water loos.

Leakage can be defined as unintentional or accidental loss of water from the pipe distribution network. Leaking pipes are major concerns for water utilities around constituting a major portion of water losses. Leakage rates are also related to length of pipes and number of connections. Improper connections can sometimes result in continuous escape of water from the distribution pipes. These water losses can be divided into two groups: the Commercial (*apparent)* losses, which consist of water volumes actually consumed but not accounted for, and the Physical (*real)* losses, that are caused by large damages that may have occurred to the network pipes or by the deterioration of the pipe junctions or the hydraulic devices (Malcolm, 2008).

2.3.1 Commercial Losses

Commercial losses, sometimes called 'apparent losses', include water that is consumed but not paid for by the user. In most cases, water has passed through the meters but is not recorded accurately. In contrast to leaks or reservoir overflows, the lost water is not visible, which leads many water utilities to overlook commercial losses and concentrate instead on physical losses. Commercial losses can amount to a higher volume of water than physical losses and often have a greater value, since reducing commercial losses increases revenue, whereas physical losses reduce production costs. Commercial losses can be broken down into four fundamental elements and those are :-(1) customer meter inaccuracy, (2) unauthorized consumption, (3) meter reading errors and (4) data handling and accounting errors (Malcolm, 2008).

2.3.1.1 Customer meter inaccuracy

Inaccurate meters tend to under-register water consumption leading to reduced sales and therefore reduced revenue. Only very rarely do meters over-register consumption. Utilities should focus initially on large customers, such as industrial or commercial users, since they consume a larger volume of water and often pay a higher tariff. Using data from accurate meters to bill customers, rather than charging them based on an assumed per capita basis, ensures that customers are charged according to their actual consumption and encourages them to preserve water (Malcolm, 2008). The paragraphs below discuss common problems with customer meter accuracies and solutions for utilities. The common possible solutions to address customer meter inaccuracy are describing as below;

1. **Installing meters properly**

Meters should be installed properly according to the manufacturer's specifications. For example, some meters require a specific straight length of pipe upstream and downstream of the meter. Therefore a standard meter stand should be designed and constructed onsite. Utilities should purchase the meters on the customers' behalf, so that only standard, high quality meters are used. Meters should also be installed where meter readers can easily read them, and where it is easy to identify each property's meter.

2. Sizing meters properly

Customer meters work within a defined flow range, with the maximum and minimum flows specified by each manufacturer. Large meters will not register low flows when the flow rate is lower than the specified minimum. Therefore, utilities should conduct customer surveys to understand the nature of each customer's water demand and their likely consumption. This information helps to determine the proper meter size for households and businesses. For customers with a high demand, checking the flow pattern and the newly installed meter verifies whether the correct meter size is used.

Problems with low flows can occur when a storage tank, with the water flow controlled by a ball or float valve, is installed on the customer's premises. These valves operate by slowly closing as the water level in the tank rises, which has the effect of reducing the flow through the meter, often below the minimum flow specification. This problem is compounded even further if the size of the storage tank is large in comparison to the customer's consumption because the ball or float valve will never fully open and the flow through the meter will be continually low.

3. Using the appropriate class and type of meter

Choosing the appropriate meter helps to ensure the accuracy of customer consumption data. Class B meters are a good choice where water quality is low, as the sediments will not greatly affect the meter. Class D meters are more preferable where roof tanks are used and water quality is good, since they have a lower minimum flow specification and will measure the roof tank inflow more accurately. Class C meters are a suitable compromise in most situations, since they can measure low flows better than Class B meters and are not as expensive as Class D meters. Common types of meters include positive displacement (PD), multi-jet, single-jet, turbine, and electromagnetic. The most common type of meter for domestic and small commercial installations is the 15 mm and 20 mm PD meter. Single-jet and multi-jet meters are more accurate for small commercial and industrial installations that require 20 mm to 50 mm sizes. Electromagnetic meters are the best choice for sizes 100 mm and above.

4. Maintaining and replacing meters properly

All meters should be installed above ground and located where they can be audited easily, including by the meter readers during their regular rounds. The utility should replace the meters systematically, beginning with the oldest meters and those in the worst condition. Poor maintenance will not only encourage inaccuracy but may shorten the life span of the meter.

Meter servicing is essential, especially in areas of poor water quality. The accuracy of mechanical meters changes over time as the mechanical bearings wear down, causing friction to increase and thus the meters to under-register. These changes will occur over a number of years, depending on the quality of manufacture. The water utility should regularly test a sample of its customer meters, including a range of meter brands and ages, using a calibrated meter test bench. This testing will determine the optimum age at which customer meters should be replaced.

2.3.1.2 Unauthorised consumption

Unauthorised consumption includes illegal connections, meter bypassing, illegal use of hydrants, and poor billing collection systems Illegal connections involve the physical installation of a connection to water distribution pipelines without the knowledge and approval of the water utility. The common problems and possible solutions are describing as below.

1) Finding and reducing illegal connections

Illegal connections can occur during the installation of a new supply connection, or sometimes the customer’s supply is cut off after non-payment and the customer cannot afford, or does not want to pay, to be reconnected. During customer awareness programmers, customers should be encouraged to report illegal connections, and regulations should be in place to penalize the water thieves. Meter readers should also report cases of direct connections without accompanying meters that they see during their rounds.

2) Tackling meter bypassing

Some customers try to reduce their water bills by using a meter bypass, which is an additional pipe installed around the meter. This bypass pipe is often buried and very difficult to detect. This type of unauthorized consumption is usually committed by industrial and commercial premises, where only a small volume of the consumption goes through the meter and the rest through the bypass pipe.

Because large customers tend to steal large volumes of water, the discrepancy will show up when the utility conducts a flow balance analysis. The utility should then undertake customer surveys and leakage step tests to determine where the missing flow occurs.

3) Preventing illegal use of fire hydrants

Although the only legal use of fire hydrants is for firefighting, some use them illegally to fill tankers (normally at night) or to provide water supply to construction sites. The utility staff can detect these flows, often high volume over a short period of time, through appropriate flow measurements at DMA meters. Such high flows are not only incidences of water theft, but also a detriment to the pipe network and water quality, which affects the service to the customer.

Through customer awareness programs, the utility staff should encourage customers to report cases of illegal uses of fire hydrants. In addition, the utility manager needs to cooperate with relevant local agencies or departments to identify owners of tankers suspected of drawing water illegally and without proper permission. Developing and enforcing regulations to penalize water thieves together with local agencies will also deter unauthorized consumption.

4) Actively checking the customer billing system

Sometimes connections are made legally, but the billing department is not notified of the new connection; therefore, the customer is never billed. These unregistered customers can be detected during the regular meter reading cycle when diligent meter readers find meters that are not in their reading book. However, this process may not identify all of the errors in the billing system.

Conducting a complete customer survey within each DMA, where by utility representative's visit every property in the DMA whether or not they are recorded in the billing system is the best method of comprehensively identifying billing system errors. The survey should include the following information: property address, name of owner, and meter make and number. The representative should also conduct a meter test to ensure that the accurate flow is recorded. For metered areas, utilities should focus on large users by encouraging good customer relationships through frequent visits. Checking large customers' accounts monthly will help detect anomalies, which may be due to water theft. In areas of suspected high commercial losses, temporary DMAs can be established to analysed flows through standard monitoring activities, such as step testing and flow balancing, to pinpoint problematic areas.

5) Avoiding corrupt meter readers

Corrupt meter readers can significantly impact a utility's monthly billed consumption. For instance, the same meter reader who walks the same route for an extended period of time, thus becoming familiar with the customers and their monthly billed consumption, may collude with those customers to record lower meter readings in exchange for a monetary incentive. To reduce this risk, the utility manager needs to rotate meter readers to different routes on a regular basis.

2.3.1.3 Meter reading errors

Errors can be easily introduced through negligence, aging meters, or even corruption during the process of reading the meters and billing customers. Incompetent or inexperienced meter readers may read the meter incorrectly or make simple errors, such as placing a decimal in the wrong place (Malcolm, 2008). Dirty dials, faulty meters, and jammed meters can also contribute to meter reading errors.

The meter readers should immediately report any observed problems, and the maintenance team should take action to remedy the problem immediately. If remedial action is too slow, meter readers may become demoralized and less inclined to report problems. Because meter readers are the utility's frontline in liaising with customers, their activities have an immediate impact on cash flow. Utility managers should therefore invest in training and motivating.

2.3.1.4 Data handling and accounting errors

The typical method of data handling and billing requires a meter reader to visit each property and read the customer meter. The data is then recorded by hand on a form, taken back to the office, given to the billing department, and typed into the billing system. A bill is then printed and mailed to the customer. In this scenario, a variety of errors may occur at the different stages: the meter reader writes down incorrect data; the billing department transfers incorrect data into the billing system; or the bill is sent to the wrong address. A robust billing database is one of the key elements of minimizing these errors and should be the initial purchase of any water utility striving to improve its revenues. The latest billing software has built-in analysis functions that can identify potential data handling errors and report them for verification. In addition, billing software will report monthly estimate readings and zero reads, both of which may indicate a problem with the customer's meter. Site visits will help identify meters needing replacement.

Training of meter readers promotes diligence, good customer meter maintenance, and decreased meter reading errors. If financially viable, utilities should consider electronic meter-reading devices, which reduce data handling errors to a minimum since all data transfers to the billing system are done electronically.

2.3.2 Physical Losses

Physical losses, sometimes called 'real losses' or 'leakage', includes the total volume of water losses minus commercial losses. However, the water balance process indicates that commercial losses are estimated and therefore the resulting leakage volume may be incorrect (Malcolm, 2008).

The three main components of physical losses include:

- ✓ Leakage from transmission and distribution mains
- ✓ Leakage and overflows from the utility's reservoirs and storage tanks
- ✓ Leakage on service connections up to the customer's meter

2.3.2.1 Leakage from Transmission and Distribution Mains

Leakages occurring from transmission and distribution mains are usually large events, sometimes catastrophic, causing damage to highway infrastructure and vehicles. The majority of such bursts are usually not very severe although they cause supply disruptions. Because of their size and visibility, the bursts are reported quickly, and are then repaired or shut off soon afterwards.

By using data from repair records, utility managers can calculate the number of leaks on mains repaired during the reporting period (usually 12 months) and estimate an average flow rate of the leaks. This gives the total annual volume of leakage from mains as follows:

$$\text{Total annual volume of leakage from mains} = \frac{\text{No. of reported bursts x Average leak}}{\text{Flow rate x Average leak duration}} \quad [2.1]$$

2.3.2.2 Leakage and overflows from the utility's reservoirs and storage tanks

Leakage and overflows from reservoirs and storage tanks are easily quantified. Utility managers should observe overflows then estimate the average duration and flow rate of the events. Most overflows occur at night when demands are low and therefore it is essential to undertake regular nightly observations of each reservoir. These observations can be undertaken either physical or by installing a data logger which will then record reservoir levels automatically at preset intervals.

Leakage from tanks is calculated using a drop test where the utility closes all inflow and outflow valves, measures the rate of water level drop, and then calculates the volume of water lost. However, repairing these leaks is a major operation, requiring draining down the reservoir and planning an alternative supply.

2.3.2.3 Leakage on service connections up to the customer's meter

This type of leakage is usually more difficult to detect and results in the greatest volume of physical losses. Utility managers should calculate the approximate volume of leakage from service connections by deducting the mains leakage and storage tank leakage from the total volume of physical losses.

2.4 Measuring Water Losses

The unaccounted for water (UFW) expressed as percentage of the total consumption and the minimum night flow (MNF) per connection are the most commonly used methods of measuring losses. UFW is the measure of losses over a period as the difference between the amount of water put in to a system and the metered or estimated quantity of water taken by consumers, while MNF is an indicator of the probable rate of losses at a given time. Night flow measured in moderately sized sectors (up to around 3000 service connections) are extremely useful for identifying the presence of existing unreported leaks and bursts, and the occurrence of new ones. However, continuous night flows can also be used for assessing annual average real losses (Farley and Trow, 2003). Unaccounted for water is a useful indicator of probable losses, but it may overestimate them because supply meters tend to under-record consumption. Many factors influence unaccounted for water and differ from one undertaking to another, standards of housing, rates of occupancy, age of mains, length of mains per 1000 population served, proportion of trade and bulk supplies, ground condition, etc. (Twort et al., 2004).

2.4.1 Calculating Real Loss Performance Indicators

Since high level of water losses, both real and apparent is a very important efficiency issue, one would assume that accurate performance indicators are used for benchmarking, international performance comparison, or target setting. However, unfortunately this with widely not the case with the exception of the UK water industry, water losses are still quoted as percentage of system input, the serious problems with this indicator were highlighted in many conferences around the world, most recently at the IWA leakage conference in Cyprus (Liemberger and Marin, 2006). The new and most advanced real loss indicators (recommended by the IWA and the AWWA) are the ILI, the infrastructure leakage index. The Infrastructure Leakage Index (ILI) is an excellent indicator of physical losses, one that takes into account how the network is managed. It is the ration of current annual volume or real losses (CARL) to unavoidable annual real losses (UARL).

ILI = CARL /UARL……………………………………………….. [2.2]

Being a ratio, the ILI has no units and thus facilitates comparison between countries that use different measurement units (U.S. metric or imperial). Nevertheless what are unavoidable losses and how are they calculated? Leakage management practitioners around the world are well aware that real losses will always exist- even in new and well managed systems (Pearson, 2005).

UARL (liters/day) =18xLm+0.8xNC+25xLP) x P……………… [2.3]

Where Lm= Mains length (km)

NC= number of service connection

Lp = total length of private pipe, property boundary to customer meter (km),

P = average pressure (m).

2.5 District Metered Area

Many water utilities operate their pipe networks as an open system where water is fed from more than one Water Treatment Plant (WTP) into an inter-connected pipe network. Water from each WTP will mix within the network, which continually affects system pressure and water quality. In an open system, NRW can only be calculated for the entire network, which is effectively an average level for the entire system. Thus, determining the exact locations of NRW occurrences and where NRW reduction activities should take place can be quite a challenge, especially for large networks (Malcolm, 2008).

Generally District Metered Areas (DMA) is a small zone (generally encompassing from 1,000 to 3,000 customer service connections) that is formed by closing valves to form a boundary, but leaving at least one measured (metered) supply pipeline open to send water into the DMA. The typical flow rates into the DMA should be sufficiently small that the emergence of a new leak produces a discernible increase in flow that alerts the operator to newly formed leakage (Malcolm, 2008). The effort to establish a DMA includes conducting a basic design on the size of the DMA and its flow and pressure characteristics. A minimum of one flow meter must be installed and other equipment (pressure sensors, communication equipment) may be desired. It may be best for a municipality to consider establishing a single pilot DMA which will provide them an opportunity to gain experience in the methodology before identifying wider areas of the distribution system for DMA use (UNEP, 2007).

2.5.1 DMA Establishment Criteria and Process

The design of a series of DMAs is very subjective, and it is unlikely that two utility engineers working on the same network would come up with the same design. The engineer typically uses a set of criteria to create a preliminary DMA design that must be tested either in the field or using a network model (Tahal, 2013).

These criteria include:

- Size of DMA (e.g. number of connections generally between 1,000 and 3000)
- Number of valves that must be closed to isolate the DMA
- Number of flow meters to measure inflows and
- Ground-level variations and thus pressures within the
- Easily visible topographic features that can serve as boundaries for the DMA

For each DMA, utility managers should develop a detailed operations manual to assist future teams in managing the water supply. The operations manual includes a schematic of the pipe network; location drawings of the flow meters, pressure control valves, and boundary valves; and a copy of the billing database for the DMA.

2.5.2 Leakage Monitoring With District Meter Area (DMA)

Once the DMA has been established, it becomes an operational tool for monitoring and managing both of the major components of NRW, physical and commercial losses. The calculation for NRW within a DMA is defined as follows:

DMA NRW = Total DMA Inflow - Total DMA Consumption……… [2.4]

After flow meters are installed on all inlets to the DMA, the Total DMA Inflow can be measured using the increase in the totalizer, or the meter counter measuring the volume of water passing through the meter, for the calculation period. The Total DMA Consumption will depend on the customer meter coverage. If the DMA has a 100% domestic meter coverage, meaning all customers within the DMA have a meter, then the total DMA Consumption can be calculated through a simple summation of all meter measurements for the calculation period.

2.5.2.1 Estimating physical losses

Physical losses within a DMA are effectively pipe leaks on the main pipes and customer connections. Leakage occurs through holes or cracks in the main pipes or at pipe joints, which will leak water constantly over a 24-hour period. In contrast, leaks from customer connections fluctuate with customer demand throughout the day, with peak demand in the morning and evening, and a minimum demand at night when most customers are asleep and not using water (Shimeles , 2011).

To estimate the level of leakage in the DMA the operator needs to calculate the system's Night Flow (NNF), which is determined by subtracting the Legitimate Night Flow (LNF) from the Minimum Night Flow (MNF). The utility will then estimate the total LNF in terms of liters per hour and liters per second (Shimeles , 2011).
To determine the level of Net Night Flow (NNF) or the portion of night flow directly attribute to leakage, subtract the LNF from the recorded MNF.

NNF = MNF – LNF ………………………………………………. [2.5]

2.5.2.2 Determining commercial losses

The level of NRW within a DMA can be calculated by subtracting the recorded consumption from the inflow. To calculate commercial losses through a simple subtraction of leakage from the NRW, as follows:

Commercial loss = NRW – NNF……………………………… [2.6]

Once utility managers identify the DMAs with significantly high commercial losses, they should investigation for faulty meters, tampered meters, and illegal connections. They may also conduct a series of customer surveys of each property within the DMA to verify the property's inclusion in the billing database, interview the occupants, and assess the water meter.

2.6 Hydraulic Performance of Distribution Networks

The concept of a network is fundamental to a water distribution model. The network contains all of the various components of the system, and defines how those elements are interconnected. Networks are comprised of nodes, which represent features at specific locations within the system, and links, which define relationships between nodes.

Water distribution models have many types of nodal elements, including junction nodes where pipes connect, storage tank and reservoir nodes, pump nodes, and control valve nodes. Models use link elements to describe the pipes connecting these nodes. In addition, elements such as valves and pumps are sometimes classified as links rather than nodes. Intelligent use of element labeling can make it much easier for users to query tabular displays of model data with filtering and sorting commands. Rather than starting pipe labeling at a random node, it is best to start from the water source and number outward along each pipeline (Amdework, 2012). In addition, just as pipe elements were not laid randomly, a pipe-labeling scheme should be developed to reflect that.

2.6.1 Principles of Network Hydraulics

In networks of interconnected hydraulic elements, every element is influenced by each of its neighbors; the entire system is interrelated in such a way that the condition of one element must be consistent with the condition of all other elements. Two basic equations that govern in Water CAD modeling network of these interconnections (Bentley Water CAD/GEMs, 2008).

- Conservation of mass or continuity principle.
- Conservation of energy or energy principle.

2.6.1.1 Conservation of Mass

For steady incompressible flow:

Net flow into junction = Use at junction

Mass in = Mass out

$$\Sigma Q_{IN} \Delta t = \Sigma (Q_{OUT} \Delta t + \Delta V_s) \quad [2.7]$$

Where: QIN = Total flow into the node (m3/s, cfs)

QOUT = Total demand at the node (m3/s, cfs)

ΔVS = Change in storage volume (m3)

2.6.1.2 Conservation of Energy

The Energy equation is known as Bernoulli's equation (Shaher, 2003). It consist the pressure head, elevation head, and velocity head. There may be also energy added to the system (such as by a pump), and energy removed from the system (due to friction). The changes in energy are referred to as head gains and head losses (Shaher, 2003).

In hydraulics, energy is converted to energy per unit weight (ft-lb/lb) of water, reported in length units (ft) called "head". Balancing the energy across any two points in system, the energy equation will be as follow: Figure 2.2 shows head losses in a pipe line.

$$\frac{P}{r} + z_1 + \frac{V21}{2g} = \frac{P2}{r} + Z_2 + \frac{V22}{2g} + h_1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{[2.8]}$$

Where: P = the pressure (Ib/ft2or N/m2)

γ = the specific weight of the fluid (Ib/ft3or N/m3)

z = the elevation at the centroid (ft or m)

V = the fluid velocity (ft/s or m/s)

g = gravitational acceleration (ft/s2 or m/ s2)

h_1 = the combined head loss (ft or m)

There are three forms of energy for Hydraulic Network Modeling of Water supply networks.

- Pressure head -$\frac{P}{r}$
- Elevation head-Z
- Velocity head - V2 / 2g

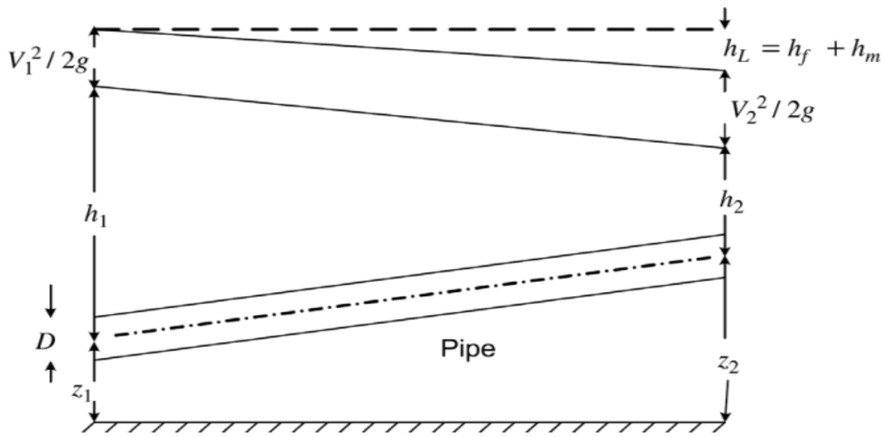


Figure2. 1 Forms of energy in water pipes

Source: (Bentley Water CADV8i/GEMs, 2008)

2.6.1.3 Water Flow Resistance (Head Loss)

The total water loss in a distribution pipe and pipe fittings between two points of consideration is called head loss. There two types of head losses.

1. Surface Resistance

Head loss on the account of surface resistance, friction loss depends on:

- Pipe length.
- Coefficient of surface resistance, friction factor.

Surface resistance is categorized as major loss.

2. Form Resistance

The form-resistance losses are due to bends, elbows, valves, reducers, and so forth categorized as minor loss.

2.7.1.4 Head Loss Equations

There are three main head loss equations. Those equations are, Darcy Weisbach, Hazen Williams and Manning which are shown in Table2.1.

Table2. 1 Head loss equations and their application area

Equation	Formula	Remarks
Manning's	$V = \frac{1}{n} R^{2/3} S^{1/2}$	This equation is commonly used for open channel flow.
Chezy's(Kutter's)	$V = C\sqrt{RS}$	Widely used in sanitary sewer design and analysis.
Hazen-Williams	$V = 0.85CR^{0.63}S^{0.54}$	Commonly used in the design and analysis of pressure pipe systems.
Darcy-Weisbach	$V = \sqrt{8g/fRS}$	Can be used for pressured pipe systems and open channel flows.

Source: (**Water CAD V8i/GEMs, 2008).**

2.6.2 Water Distribution Modeling

A model is a tool that can be used to determine the likely response of a system to a given set of stimuli without having to actually impose those stimuli on the system. Today, water distribution modeling is a critical part of designing and operating water distribution systems that are capable of serving communities reliably, efficiently, and safely, both now and in the future (Bentley Water CAD/GEMs, 2008).

2.6.2.1 Water CAD

Water CAD is a powerful, easy-to-use, which is:

- A water distribution modeling software;
- Used in the modeling and analysis of water distribution systems;
- Used for firefighting flow and constituent concentration analyses, energy consumption and capital cost management; and
- Popular for water supply design.

Water CAD provides sensitive access tool needed to model complex hydraulic situations. Some of the key features allow us to:

- ❖ Perform steady state and extended period simulations.
- ❖ Analyze multiple time-variable demands at any junction node.
- ❖ Quickly identify operating inefficiencies in the system.
- ❖ Perform hydraulically equivalent network skeletonization including data scrubbing, branch trimming, and series and parallel pipe removal and efficiently manage large data sets and different “what if” situations with database query and edit tools (Amdework, 2012).

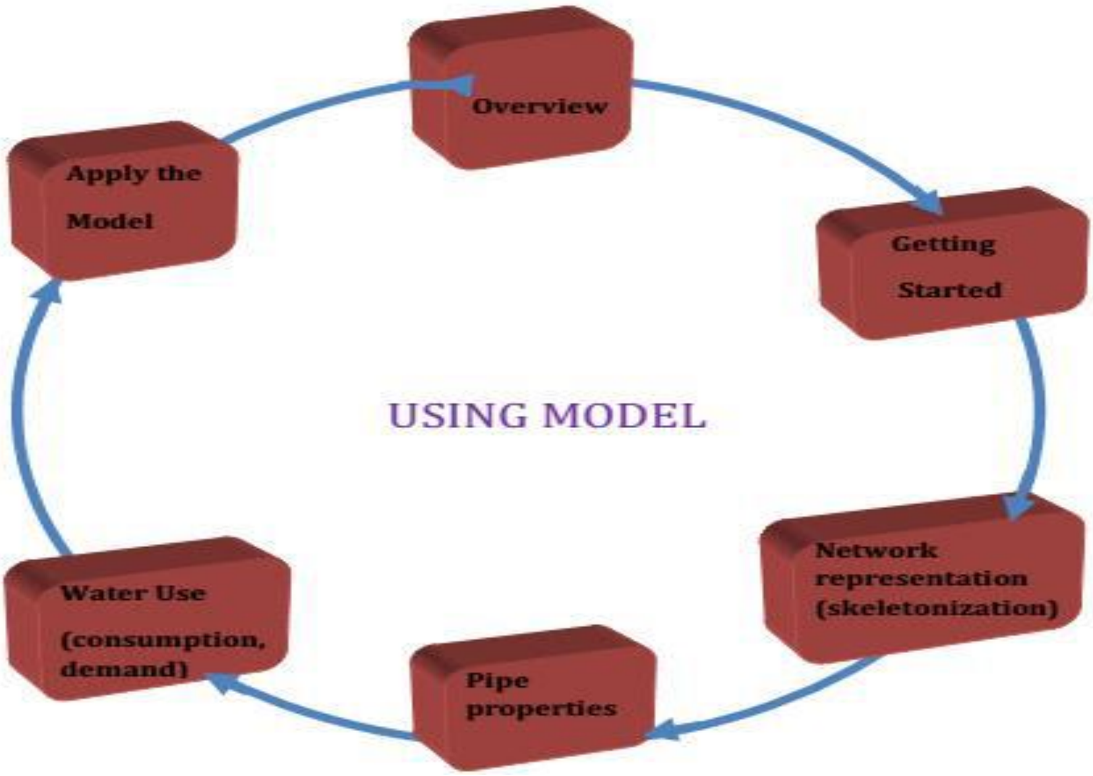


Figure2. 2 Diagrammatical representation modeling process

Source (WaterCAD V8*i*/GEMs, 2008).

2.6.3 Water Distribution Simulation

Simulation refers to the process of imitating the behavior of one system through the functions another. In our case, the term simulation refers to the process of using a mathematical representation or real system, called a model. Simulation can be used to predict system responses to under a wide range of conditions without disrupting the actual system, and solutions can be evaluated before time, money, and materials are invested in a real-world project (Bentley Water CAD/GEMs, 2008).

There are two most basic types of simulations that a model may perform, depending on what the modeler is trying to observe or predict. These are:

- Steady state simulation.
- Extended period simulation (EPS).

2.6.3.1 Steady State Simulation

A steady-state simulation provides information regarding the equilibrium flows, pressures, and other variables defining the state of the network for a unique set of hydraulic demands and boundary conditions. Steady-state models are generally used to analyze specific worst-case conditions such as peak demand times, fire protection usage, and system component failures in which the effects of time are not particularly significant (Mitchell et al., 2009).

2.6.3.2 Extended Period Simulation

Extended period simulation tracks a system over time, and it is a serious of linked steady state run. The need to run extended period simulation is because the system operations change over time.

- Demands vary over the course of the day.
- Pumps and wells go on and off.
- Valves open and close.
- Tanks fill and draw.

Simulation Duration: An extended-period simulation can be run for any length of time, depending on the purpose of the analysis. The most common simulation duration is typically a multiple of 24 hours, because the most recognizable pattern for demands and operations is a daily one.

2.7 Aqua Lite Water Balance Software

2.7.1 General

In recent years there has been a growing realization that a standard methodology and terminology is required to assist Water Utilities in assessing the water balance of their systems.

A transition from traditional familiar terminology and methods is never easy to accomplish, and a commitment is needed from all Water Suppliers if improved assessment and comparisons of water losses are to be implemented. It is possible to account for all water entering a water distribution system. Water Utilities using Aqua Lite will be able to express their water balance using the standard International Water

Association (IWA) terminology to assess the levels of Real Losses and Non-Revenue Water in their systems (AAWA, 2002).

Aqua Lite also calculates the ‘Unavoidable’ annual real losses for any system exceeding 5000 service connections. This calculation is based on the Length of Mains, Length of Underground Pipe from Street Edge to Customer Meter (optional and not required in many countries), Number of Service Connections and Average Operating Pressure. Once calculated, the Unavoidable Annual Real Losses are used to produce a new and versatile Performance Indicator for Real Losses the Infrastructure Leakage Index (ILI) which is the ratio of the Current Annual Real Losses to the Unavoidable Annual Real Losses (Ronnie, 2010).

2.7.2 Purpose of Aqua Lite Water Balance Software

Aqua Lite is designed to assist water suppliers in creating an annual water audit for a specific water supply system. The original intention of the model is to allow a Municipality or Metro to complete an annual water audit for the whole supply system. The model can, however, also be used to complete a water balance for a portion of a larger system and in this manner it can be used to identify areas which experience abnormally high levels of leakage (Ronnie, 2010).

The model is used to create an annual water balance for a specific water supply area based on the available data concerning the water supplied to the system and the breakdown of the water that can be accounted for by the supplier. The model provides a summary of the water balance in the standard International Water Association format and also provides a selection of performance indicators which can be used to evaluate the levels of leakage as well as the effectiveness of the management of the system (AWWA M36, 20014).

CHAPTER THREE

MATERIALS AND METHODS

3.0 Introduction

Based on the research objectives and questions stated in the introduction chapter the method how the research will be carried out is discussed in this chapter. The methods of data collection and data preparation are also discussed in this chapter. Generally, the research is divided in to two major parts, analyzing the water supply coverage and the water loss analysis. The monthly water production and consumption data was used to evaluate the water loss at all levels. After evaluating the water loss, the causes for the loss was tried to be identified using the different factors that have an impact to the water loss like the pipe ages, the ground elevation (topography) and customer meter records.

3.1 Description of the Study Area

Akaki Kality sub city is one of the ten sub cities of Addis Ababa and consists of eleven woredas. It is located in the southern parts of the city and from total area of Addis Ababa, 23.7 %(12,797.36ha) areas are defined by Akaki Kality Sub-city. The total production from Akaki catchments is about 32% of the total recharge. Out of which 28% is used for AAWSA production. Akaki Kality has at about 181,200 people (CSA, 2007); among them 46648 are registered customers of AAWSA Akaki-branch office.

The study area is the only sub-city in the Addis Ababa largely relies on ground water as its main source for drinking purpose. From eight branch of AAWSA, Akaki branch is the one which covered Akaki Kality sub city administration of Addis Ababa. The Akaki branch office is found in Akaki Kality woreda 01 at the east of Addis Ababa by 23km away from main office of AAWSA which is found at Megenagna area.

3.1.1 Location

Akaki Kality sub city is located at the south of Addis Ababa and it borders with Bole sub city in the north, Nifasilk lafto sub city in the west, Oromia in the south and east. Geographically the sub city is located 8.89N in latitude and 38.79E in the longitude and its altitude ranges from 2000m - 2800 m above sea level.

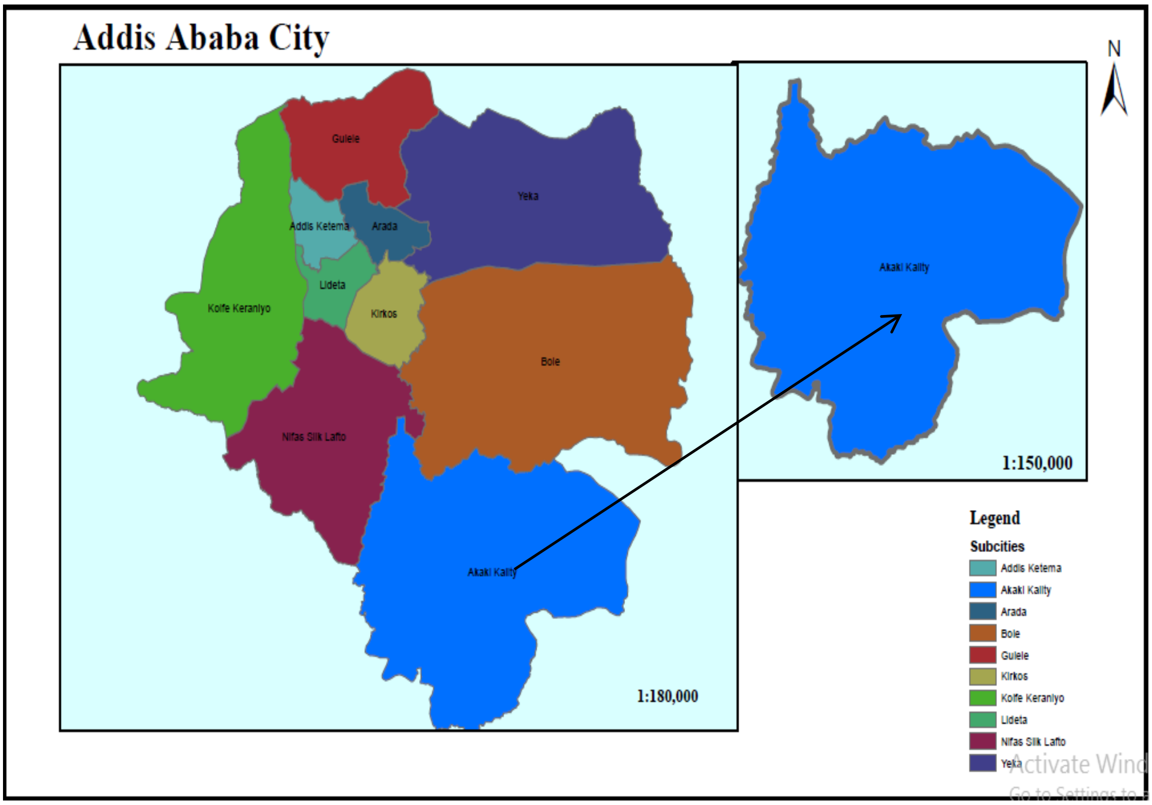


Figure3. 1 Location of the study area

3.1.2 Climate

According to National Meteorological Agency of Ethiopia, Akaki Kality mean minimum and maximum temperature of the day varies from season to season; however, the variation is not too large. Mean minimum temperature varies from 7°C to 11°C and mean maximum varies from 21°C to 25°C. For month of December mean minimum temperature is 7°C and mean maximum temperature is 23°C. For month of May mean minimum temperature is 11°C and mean maximum temperature is 25°C. From June to mid-September is main rainy season for sub city with a short wet season in April (National Meteorological Agency of Ethiopia, 2016).

3.1.2 Water Supply and Distribution System

The sub city has started getting water supply in 1901. During the years between 1942 and 2010 many water supply projects have been implemented that the construction and upgrading of ground water , improvement of the distribution, ground water and spring (wells) development of among them (AAWSA, 2012). Currently around 30850.19

m^3/day water is produced from different sources; there is Fanta Spring, Akaki Wells, and Gebreil Well.

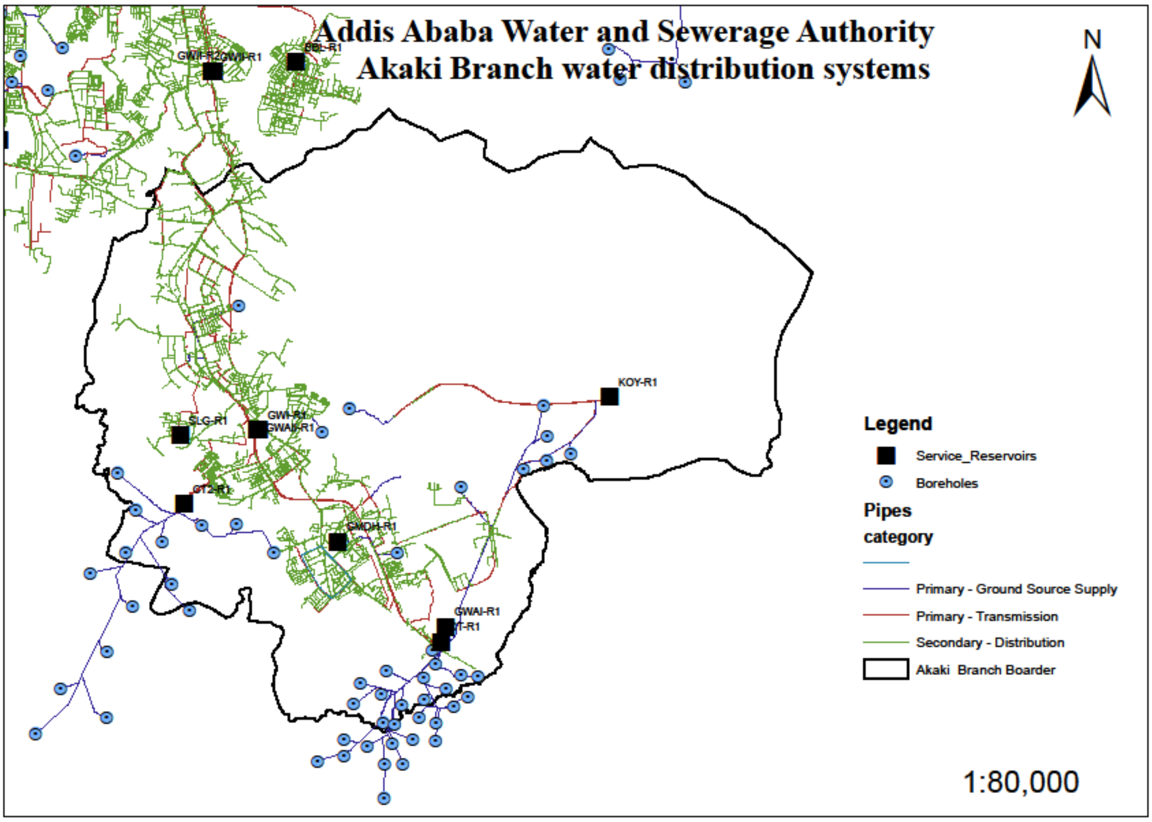


Figure3. 2 Water Supply and Distribution System of Akaki Branch

Source: Addis Ababa Water and Sewerage Authority Akaki branch office, 2017

3.2 Method of Data Analysis

The water supply coverage of the sub city was first evaluated before analysing the water loss. In evaluating the water supply coverage the focus was on the volume of consumption and level of water connection as these are highly related to the issue of water loss. The total water produced and the actual water consumption as aggregated from the individual contracts (customer meters) were used as an input for sub city level analysis, while for the local level analysis, data on water production and consumption that has been previously recorded by AAWSA for monitoring purpose was used.

3.2.1 Selection of Sample Site and Size of the Study Areas

The sample sites were selected by gathering information from AAWSA Akaki branch office where the shortages of water available in the Akaki Kality sub city administration or Woreda.

Generally, the following main criteria have been considered in the selection of the sample area.

- Availability of data. As water production data for specific locations and all the sites are taken for analysis.
- Topographic condition of the sub city
- Suitable sites for transportation during collection of customer data and taking reading.

Taking the above criteria in to consideration 5 DMA were selected for sample site in Akaki Kality sub city. Taken for evaluating the distribution of water supply coverage including the five sub-systems are also located. Those selected sites are:

1. Salo Addis Sefer Areas, DMA1
2. Woreda 08 Derartu School Areas, DMA2
3. Kality(woreda 7) KK-Textile Factory Areas, DMA3
4. Kality Around Cheralia Condominium Areas, DMA4
5. Akaki Areas, DMA5

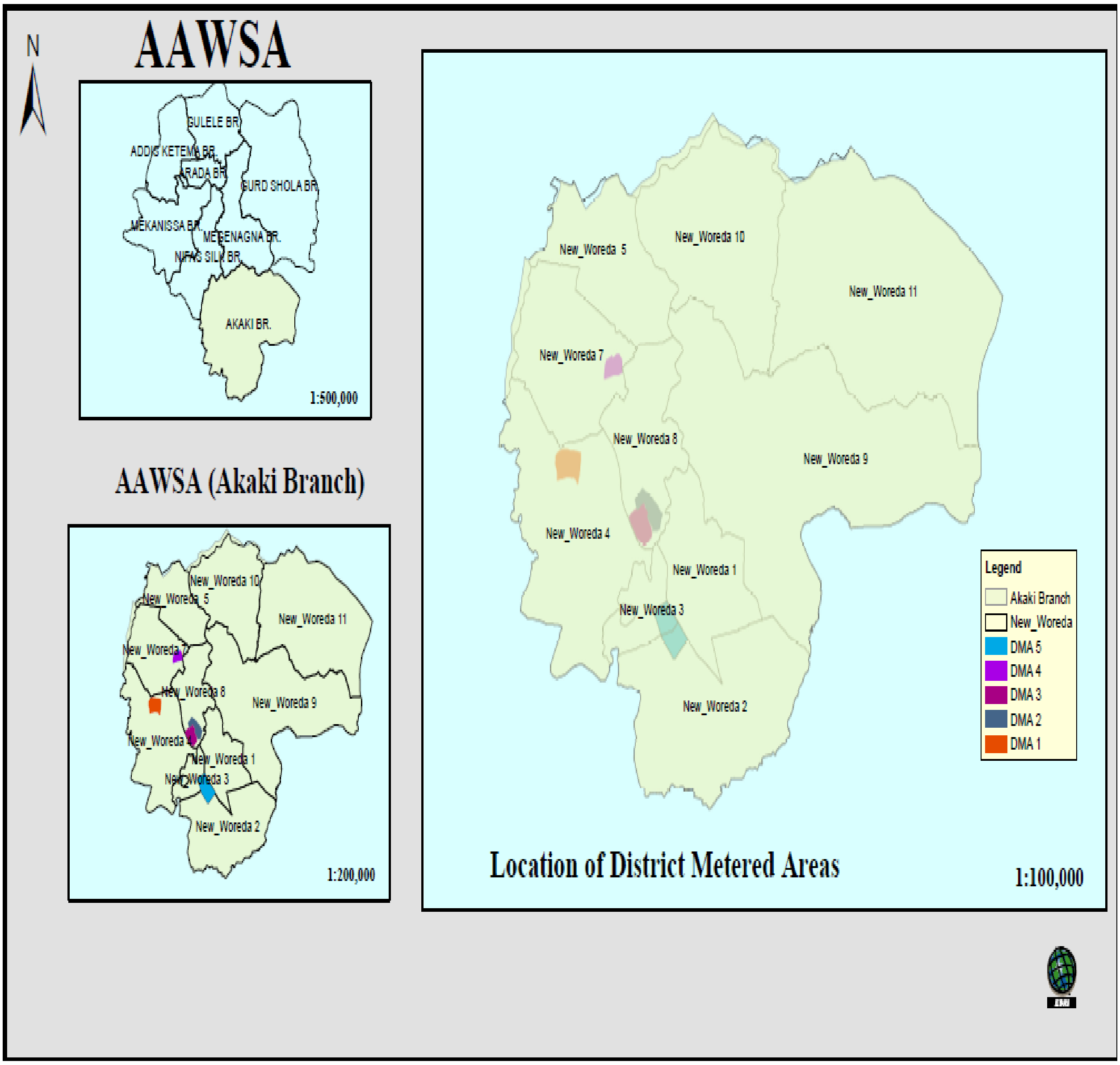


Figure3. 3 Location map of sampling Pilot District Metered Areas done

In each DMA there is 400-1400 number of customers for sample size in the study area. To investigate leakage prone points in the system pressure readings during the 24 hours at different zones were taken. These pressure readings were also used to determine the average pressure of the distribution system that is vital in the calculation of unavoidable annual real loss. In conjunction elevation readings were also taken at same zones that is planned to verify the relation between pressure and elevation.

3.2.2. Water Supply Coverage

The water supply coverage of the city has been evaluated based on the average per capita consumption and level of connection per family. The average per capita consumption has been derived from the yearly consumption of each customer that has been aggregated from the individual customer water meters. Beside to the average per capita water consumption, the distribution number of domestic's connection per family has been also evaluated. Number of population as forecasted to the year 2017 has been used to evaluate the average per capita consumption.

3.2.3. Water loss analysis

In order to identify the total loss of water in the city, the total volume of water supplied to the network distribution system was compared with the actual water consumption. In this case, the data on consumption were aggregated to sub city level. Although the data has been collected for each customer meter or contract of the entire sub city, the water loss analysis has been done focusing at the selected area (District Metered Area) level that data is found.

3.3 Data Collection

To acquire the required information needed to meet the objectives of the study, both primary and secondary data were collected from the AAWSA Akaki branch office and field. Some supplementary information was also collected from other respective offices and supportive qualitative information through discussion with local experts of AAWSA.

3.3.1 Primary Data Collection

The primary data gathering technique include household survey, field visit, questionnaires, key information interviews, focus group discussion, and personal observation and informal discussion.

Observation: In order to make the research actual on site observation technique was carried out.

3.3.1.1 Pressure Measurement

Pressure measurement throughout the entire day was conducted at different zones in the distribution system. At location where pressure gauges were installed, elevation readings were also taken. Critical times were selected while pressure gauges were taken. These critical times were fixed based on the demand rate of the users which covers the time between 8:00-12:00 (early mid noon) 2:00-6:00 (afternoon) 8:00-12:00 (early mid night) and 2:00-4:00 (early morning) (Lambert, 2004).

Sampling location

A typical network representation of a water network may include hundreds or thousands of links and nodes. Ideally, during the water distribution model calibration process is adjusted for each link and each node. However, only a small percentage of representative sample measurements can be made available for the use of model calibration due to the limited financial and labor requirements for data collection.

Twelve representative samples have taken; according to (USEPA, calibration Guidelines) throughout the study area for calibration and located on Figure 3.4 below on the distribution network. Pressures were measured in the field in order to compare with the results of the distribution model by using Pressure Logger instrument. According to operational case criteria the sample size consideration has been taken:

1) Number of pressure reading 10%-2% of nodes and accuracy of pressure readings ±2psi (1.4m)
2) Number of flow reading in the pipe 2% of pipes and accuracy of flow readings ±5%.

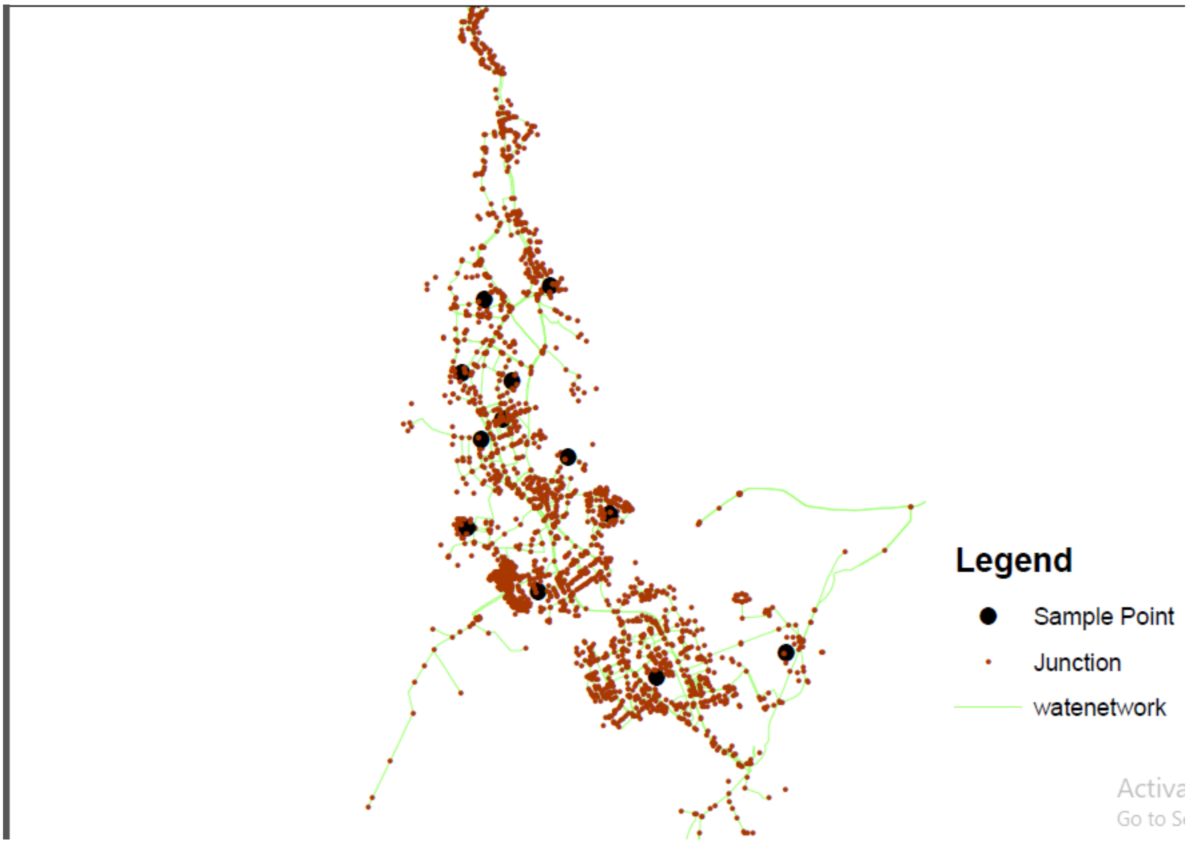


Figure3. 4 Location of sampling site in distribution system

Source: Adapted from Ethio GIS by AAWSA water distribution network, 2017

As shown in above Figure 3.4 field investigations were done to identify the existing situation of the study area and based on reconnaissance survey twelve sampling sites were selected to determine the average operating pressure for the calculation of unavoidable annual real loss and the distribution system each zone is vital for model calibration.

3.3.2 Secondary Data Collection

3.3.2.1 The Sub City Water Supply Networks

The entire Akaki Kality sub city water supply network including their attribute like the length, diameter, material types, pressure capacity of the pipes, pumps characteristics, reservoir and tank section has been collected from the AAWSA main office and branch office. The collected pipe network mainly comprises of main pipes and secondary pipes that covers the major part of the sub city. The length of the entire network was summed up according to their diameter of further determination of unavoidable annual real loss.

The data on the network were found from two sources within AAWSA, one from the Auto cad and GIS unit that contains both the main and secondary pipes and the other from the planning department of the authority.

3.3.2.2 Number and Type of Customers Meter

The number and type of customers with their corresponding meter type has been collected from the AAWSA Akaki branch office that can be used in the determination of real and apparent loss. The length of service connection is also summed up as it is required for the determination of real loss in the distribution system.

3.3.2.3. The Sub City Water Reservoirs

The information on location of most of the water reservoirs were collected in conjunction with the main water network on the city. The reservoir's data including their capacity, years of construction and material of construction were also collected.

The locations of some of the reservoirs were not exactly indicated in the network, and the document found from the planning department indicates only the surrounding where they are located. To get further information rather than obtain from branch and head office of AAWSA, visiting the site within the branch technician also considered. At the time of field visit, all necessary data especially their location of all service Reservoir which found in Akaki Kality sub city are collecting and described as follows.

Table3. 1Service Reservoir found in Akaki Kality Sub City

S.No	Reservoir Name	Capacity (m^3)	Elevation (m)	GPS Location	
				X-Coordinate	Y-Coordinate
1	GaraMedihaniyalem Reservoir	153	2152	476993	980138
2	Koye Reservoir	150	2273	482616	983115
3	Salogiorgis Reservoir	800	2165	473559	982315
4	New City Reservoir	2000	2070	473836	980882
5	GW I Reservoir	1500	2135	475342	982418
6	GW II Reservoir	5000	2221	474429	989798
7	Tullu Dimtu	800	2149	479266	988370

Source: AAWSA Akaki branch office, 2017

3.3.2.4 Water Meter Testing

The customer meters currently in use by AAWSA are many different manufacturers and countries of origin. All customer meters which are currently in use or are available in stock are of the meteorological class B according to ISO 4064 Edition 1993. Existing customer meters for each of the eight Branch Office are of ½’’, ¾’’, 1’’, 1.25’’ and 1.5’’ diameter are of the velocity single jet or velocity multi jet type. Larger customer meters (of 2’’, 2.5’’, 3’’, 4’’, 5’’, and 6’’) are mostly Woltman-type turbine meters. The aim of customer meter testing is to obtain data on existing customer meter performance which will lead to a reliable assessment of the present level of apparent water losses in AAWSA's water distribution system and to the preparation of reliable water audits.

3.3.2.5 Water Production

The main sources of water supply for the sub city are the ground water scheme and a number of wells and springs. According to the information found during discussion with the experts from the authority, almost no other water sources were available apart from the wells and springs that were already included to the city distribution network. The water supply obtains from this Akaki ground well and spring is also used for other sub city. So the water production was collected from each wells and springs which are described in Table 3.2

Table3. 2 List of water supply sources which supplies for Akaki Kality with their GPS location

S. No	Name	Types of Sources	GPS Location		Elevation(m)	Operating Hours(hr)	Optimum Yield(l/s)
			X-Coordinate	Y-Coordinate			
1	Kality Gabriel-1	Bore hole	475300	984900	2120	18	15
2	Kality Gabriel -2	Bore hole	474612	984876	2084	24	31
3	Fanta-1	Spring	480847	981623	2152	12	12
4	Fanta-2	Spring	481322	981799	2166	12	18
5	Akaki-1	Bore hole	477252	982872	2066	12	14
6	Akaki-2	Bore hole	476692	982390	2068	12	4
7	EP-4	Bore hole	479684	976953	2085	22	24
8	EP-5	Bore hole	478450	979950	2120	6	11

Source: AAWSA Akaki branch office, 2017

According to the draft document of Sector Development Program of AAWSA, currently around 11,145.6m^3 per day water is distributed from a number of Akaki ground water wells and springs. There are no other water sources available apart from the wells and springs that were already included to the city distribution network.

3.3.2.7 Water Consumption

In order to evaluate the water loss in the distribution system, consumption data of each customer were collected from the computer information section of AAWSA Akaki branch. The end of December 2017, there are 46648 numbers of customers in Akaki branch within the entire Akaki Kality Sub City. Water consumption in this context is metered billed and unbilled authorized consumption.

3.3.2.8 District Metered Areas Preparation

District metered area is a method or a technique used to reduce water losses and also indicate the extent of water losses. The implementation of five pilot District Metered Areas serves the purpose of obtaining an assessment of real water losses in AAWSA's Akaki branches water distribution system and assessment of real water losses. For preparation of DMA the primary data collected from the field is taking reading of customer water meter before and after taking action by installing existing or new valves on inlet and outlet.

Equipment Used for Collecting of DMA Data

The equipments that were made available by AAWSA for use in Active Leakage Control included one or two items of each of the following during we collect data with in Akaki office technicians.

- **Correlato**r – Manufacturer: Sewerin, Model: SeCorr 08 used for pinpointing a leak in a section of the pipe.
- **Ground microphone** – Manufacturer: Sewerin, Model: Aquaphon A100 used to verify the presence of leaks in a specific place.
- **Small listening stick** – Manufacturer: Sewerin, Model: Stethophon 04 used for listening on pipes and identify leak noise.

- **Cable and pipe locator** – Manufacturer: Sewerin, Model: UT 830 used for tracing the path of buried metal pipes and cables
- **Metal Detector** – Manufacturer: Sewerin, Model: Cover Locator used for pinpointing buried metal cover and equipment.

3.3.2.9 Population and other documents

Based on the CSA (2007) and the numbers of the population forecasting by CSA in the year 2015,2016 and 2017 has been also collected from planning commission of the Akaki Kality sub city office. To analyze the existing water supply coverage of Akaki Kality, the projected population data of the sub city which obtained from CSA were used and presented in Table 3.3.

Table3. 3 Population of Akaki Kality Sub City for the years of 2015-2017

Year	Projected Population
2015	216,538
2016	221,759
2017	227,182

Source: Akaki Kality Planning Commission Office, 2017.

Beside to these, some relevant documents were collected from the branch of water authority and also secondary data were collected from Addis Ababa Water and Sanitation Development and Rehabilitation Project Office and Ethiopian Mapping Agency and by method of document review and other related journals, articles, newspapers, magazines and from internet.

3.4 Methods of Data Analysis

3.4.1 Water Supply Coverage Analysis

The water supply coverage of the sub city has been evaluated based on the average per capita consumption and by mode of service. The average per capita consumption has been derived from the yearly consumption that was aggregated from the individual water meters. Besides to the average per capita water consumption, the distribution of number of domestic mode of service has been also evaluated.

3.4.1.1 Average daily per capita consumption

The annual consumption data has been converted to average daily per capita consumption using the number of population. The average daily per capital consumption of Akaki Kality sub city was derived using the following expressions:

$$\textbf{Capita consumption (l/person/day)} = \frac{\textbf{Annual consumption } (\mathbf{m^3}) \times \mathbf{1000 l/m^3}}{\textbf{Population number of Sub City} \times \mathbf{365}} \ldots\ldots [3.1]$$

3.4.1.2 Level of Connection per Family

Level of water connection is an important element on the one hand for evaluating the level of water coverage that was focus of on this section and on the other hand it has a direct impact on the water losses that were dealt separately. According to CSA, statistical report of 2010, average family size of 5.5 is used for calculating the average number of connection per family using the following expression.

$$\textbf{Connection per family)} = \frac{\textbf{Total number of connection of the sub city}}{\textbf{(Number of population of the sub city/Average family size)}} \ldots\ldots\ldots\ldots [3.2]$$

3.4.2 Water loss analysis

The total annual water produced and distributed to the distribution system and the water billed that was aggregated from the individual customer meter readings were used to quantify the total water loss for the sub city. All the water consumptions in the city were metered except very few like for firefighting use and water used by the water authority itself. As the authorized non-metered consumption are insignificant while compared with the total water production, the unaccounted for water (UFW) has been used as a synonymy of the total water loss in this analysis. Total water loss is calculated as follows.

$$\textbf{Total water loss (\%)} = \frac{\textbf{(Total water produced – Total water billed)*100}}{\textbf{Total water produced}} \ldots\ldots\ldots [3.3]$$

3.4.2.1 Unavoidable Annual Real Losses (UARL)

Considerable work was undertaken to assess the minimum level of leakage for any system (Lambert et al 1999) and after careful analysis a relatively simple and straightforward equation was developed as follow

UARL (liters/day) =18xLm+0.8xNC+25xLP) x P……………………… [3.4]

Where Lm= Mains length (km) NC= number of service connection Lp = total length of private pie, property boundary to customer meter (km) P = average pressure (m).

3.4.2.2 Calculating Infrastructure Leakage Index

The ILI indicators are defined as a ration of real losses (RL) and unavoidable annual real losses (URAL). It is a new indicator of water supply systems expressing the technical condition of the system from the point of view of water loss. This indicator is proposed and recommended by the international water association IWA (Lambert et al, 2008). The ILI calculation uses simplified values of non-revenue water (NRW) as

ILI = NRW/UARL………………………………………... [3.5]

Where, NRW = non-revenue water (m3/year

UARL= unavoidable annual real loss (m3/year

In addition, the water loss in the water supply distribution system was evaluated using Aqua Lite Water Balance Software. Detail analysis of the water loss components has been explained using the Aqua lite water balance software in section 3.4.8.

Non-revenue water

Non-revenue water (NRW) represents the difference between the volumes of water delivered into a network and billed authorized consumption.

NRW =Net production – Revenue water…………………………….. [3.6]

= UFW + water which is accounted for, but no revenue is collected (unbilled authorized consumption)

3.4.3 Analysis of hydraulic performance

The hydraulic modeling software **Bentley Water CAD V8*i***" simulation was carried out for the purpose of pressure regime for customers demand, velocity, and head loss and overall systematically studding and better understand network operation.

These Software capabilities include graphical editing; image, CAD and GIS background support; steady-state and extended-period simulation; rule-based controls; pressure dependent demands; GIS interface for import/ export of data and results; automatic nodal demand allocation; pipe length-based demand loading, ground elevation extraction from shape files and CAD drawings, pressure zone management and automated model calibration.

3.4.4 Model Analysis

Analysis of the model of existing system has been made by running the model at current year daily average, at peaking and temporal variations of demand with different scenarios.

3.4.4.1 Steady state Analysis

The model has been performed in steady state run for the average daily demand, which is the demand at every node not changing throughout 24 hours of a day. The software simulates Steady-State hydraulic calculation based on mass and energy conservation equations principle.

3.4.4.2Extended Period Simulation

The system conditions have been computed over twenty-four hours with a specified time increment of one hour and starting model run time. The software simulates non steady-State hydraulic calculation based on mass and energy conservation principle. The model can be simulated for every one-hour time setup in the twenty-four hour duration.

3.4.5 Population Forecasting

Direct population count and projection based on pre-counted population are two possible approaches to collect population data. However, since direct population count at any time requires a great deal of resource and time, it is not usually preferred. Different population forecasting methods are in fact available and can be used for population projection. But their result varies from one method to another. For fast growing city, where relatively high economic activity is observed and at the same time continuous expansion of city due to various reasons is experienced, exponential method population forecasting is preferably used (Ministry of Water Resources of Ethiopia, 2012). Exponential population forecasting method is expressed as follows;

$$P_n = P_o e^{rn} \quad \text{[3.7]}$$

Where, P_n= population at year n

P_o= base year population

e = constant e, the base of natural logarithm

r = population growth rate

n =projection year

In order to forecasting population up to 2037 of the study area based on last population census report (2007) - population and housing census report of 2007 which was prepared by Ethiopian Central Statistical Agency (CSA) was accessed mainly to establish base population.

3.4.6 Demand Estimation

Projected population figures, per-capita demand and percentage share of different mode of services are important parameters for water demand estimation of the project for the anticipated design periods. Water consumption varies according to the mode of services, climatic conditions, socio-economic condition and other related factors (Ministry of Water Resources of Ethiopia, 2012). After reviewing previous design criteria in the Addis Ababa city, the following per capita water consumption were followed.

3.4.6.1 Domestic Demand

The water demand study is very vast and the estimation was made by comparing the consumption with other relevant similar towns of the country. However, there are some findings, like category of mode of services, though the percentages vary and hourly variation of demands, that highly contribute to estimate reasonable demand for the design periods.

Based on the service level and level of consumption, domestic water demand can be categories as:

- House connection (HC)
- Yard connection, (YC)
- Yard shared connection (YSC)
- Public taps (PT)

The values of service level and per-capita consumption are taken depending CSA data and forecasting population which can put by category depending on population. So after calculating population we know the interval of categories in each year and after that the average daily domestic demand of the city is calculated by multiplying the number of people using a certain connection type with the per capital demand associated with that connection type.

These are expressed as:

$$\mathbf{DD_Y = P_Y\,(HC_Y{*}PC_{HC,Y} + YC_Y{*}PC_{YC,Y} + YSC_Y{*}PC_{YSC,Y} + PT_Y{*}PC_{PT,Y}).\ [3.8]}$$

Where DD_Y = Domestic demand in year y

P_Y = Population in y year

HC_Y = Percentage of people using house connection in y year

YC_Y = Percentage of people using yard connection in y year

YSC_Y = Percentage of people using yard shred connection in y year

PT_Y = Percentage of people using public tap connection in y year

$PC_{HC,Y}$ = Per capital water demand of people using house connection in year

$PC_{YC,Y}$ = Per capital water demand of people using yard connection in y year

$PC_{YSC,Y}$ = Per capital water demand of people using yard shared connection

$PC_{PT,Y}$ = Per capital water demand of people using public tap connection in y

3.4.6.2 None Domestic Demands

This demand includes water required for other purposes like residential, industrial, commercial and institutional. The public gardens and parks, washing the cars, etc are also included in this category.

Estimation of nondomestic demand requires a detail investigation of existing and planned industries to be developed in the area. It is also crucial to clearly identify the scale of the industries as it directly affects their water demand thereby putting influence on the overall water consumption pattern of the sub city. This method, however, needs well organized data base recording of the type and scale of water demands of different industries. However, there is no well-organized data indicating the type, scale and water consumption pattern of different industries found in the sub city. Due to this, there is no well-organized data which indicating the type, scale and water consumption pattern of the industrial, commercial, institutional, etc in the sub city, the amount of nondomestic demand is expressed as a percentage of domestic demand. And the value is fixed after forecasting population for identified the category depending on CSA.

3.4.6.3 Fire Fighting

Water demand for firefighting purposes shall be assessed on a town-by-town basis, depending on the existence of equipment and the capacity of any firefighting service. In Addis Ababa city, fire hydrants shall be installed at public and municipality interest such as schools, shops, hospitals, fuel stations and at other situation places and salient points of distribution network

The volume of water required for firefighting is determined based on different factors among which fire incidence, duration, water flow in distribution system, density and size of buildings and building construction materials are the main (Larry W., 2004). Based on these factors, there are different methods developed to determine the firefighting demand for a certain location. The criteria set by Federal Democratic Republic of Ethiopia Ministry of Water Resource for firefighting demand estimation is to increase the capacity of service reservoirs dedicated for the area by 10.

3.4.6.4 Unaccounted for water

Unaccounted for water (UFW) is expressed as a percentage of the total water produced for the system. UFW for water include water losses due to leakage in the water supply system, illegal connections, legitimate unmetered for flushing, overflow from reservoirs, improper metering and others for which bills are not paid. To be economically, the proposed value of unaccounted for water to be from 25 to 40% of the domestic water demands and the value is fixed after forecasting population for identified the category depending on CSA.

3.4.6.5 Adjustment Factor

1. Adjustment due to socio-economic factors

Socio-economic factors determine the degree of development the city is shown in Table 3.4

Table3. 4 Adjustment factor due to socio-economic condition

Group	Description	Factor
A	Towns having living standard& with very high potential	1.1
B	Towns having a very high potential for development but lower	1.05
C	Towns under normal Ethiopian condition	1.0
D	Advanced rural	0.9

Sources: CSA (2007) Statistical Report on Housing Characteristics of Addis Ababa

Generally in Addis Ababa and particularly in Akaki Kality sub city, 1.0 is used as towns under normal condition.

2. Adjustment due to climate effect

Table3. 5 Adjustment due climate effect

Group	Mean annual rainfall in mm	Factor adopted
A	900 or less	1.1
B	900 – 1200	1.0
C	1200 or more	0.9

Sources: CSA (2007) Statistical Report on Housing Characteristics of Addis Ababa According to National Meteorological Agency of Ethiopia, the mean annual rainfall of Akaki Kality is found in the range of 900-1200mm and so 1.0 adopted factor is used for adjustment in future demand projection.

3.4.6.6 Demand Variations

Water flow in the distribution system varies between the months of a year, days of a week and hours of a day. The following demand conditions should be taken into consideration:

• *Average Daily Demand*

This is the sum of the demands of domestic, commercial, institutional, industrial, public and unaccounted-for water (losses).

• *Maximum Daily Demand*

The water demand varies from day to day. The maximum day water demand is considered to meet consumption changes with seasons and days of the week. The ratio of the maximum daily consumption to the average annually daily consumption is the maximum day factor. The value maximum daily factor is proposed depending on the population number of the city which is presented in Table 3.6.

Table3. 6 Maximum day demand factor

City Population	Maximum daily factor
0 to 20000	1.3
20001 to 50000	1.25
50001 and above	1.2

Sources: CSA (2007) Statistical Report on Housing Characteristics of Addis Ababa

Depending of the sub city population which is above 50,001, 1.2 maximum daily factor is used in demand calculation.

• *Peak Hourly Demand*

The peak hourly demand is determined by multiplying the average daily demand by the peak hourly factor. The peak hourly factor was determined based on the projecting population which presented as follows:

Table3. 7 Peak hour demand factor

City Population	Peak hourly factor
0 to 20000	2.0
20001 to 50000	1.9
50001 to 100000	1.8
100000 and above	1.6

Source: CSA (2007) Statistical Report on Housing Characteristics of Addis Ababa

Based on the population of Akaki Kality sub city which is 181,200 and above 100,000, the peak hourly factor used is 1.6.

3.4.7 District Metered Areas Preparation

In order to prepare DMA the following methods and instruments are used.

1. Gathering information and selecting the area depending where the leakage may more.
2. Determine the boundary of DMA depending on water network map in office
3. Identify and isolate the selected area from other systems by installing water meter at inlet and outlet and also install additional gate valve where necessary.
4. After fix all mentioned above, take 1st and 2nd reading without any loss reduction actives
5. Know or calculate the loss in the systems in percentage depending on 1st and 2nd reading.
6. Assess the leakage and take an action to reduce the loss
7. To locate the possible location of leakages, the following methods with combination of equipment could be used. Walking over the mainline, for looking the signs that shows presence of water.
8. After maintenance at all leak point and changed aged water meter in the system take the 3rd reading.
9. After maintenance at all leak point and changed aged water meter in the system take the 4rd reading.

To locate the possible location of leakages, the following methods with combination of equipment could be used by walking over the mainline, for looking the signs that shows presence of water, Non Electronic Equipment and Electronic Equipment's.

After all action takes place, water loss was analysed as:

Water loss = water supplied to the system- water used by customers in the system [3.8]

$$\textbf{Water loss in percentage} = \frac{\textbf{Water loss in the system}}{\textbf{water supplied to the system}} X100\% \text{ .... } [3.9]$$

3.4.8 Aqua Lite Water Balance Software Analysis

Aqua Lite is designed to assist water suppliers in creating an annual water audit for a specific water supply system. The model provides a summary of the water balance in the standard International Water Association format and also provides a selection of performance indicators which can be used to evaluate the levels of leakage as well as the effectiveness of the management of the system.

To complete this water audit software having selected the data file to open or having created a new data file and completed in the basic as order shown.

- **System Data** (input of basic system data)
- **Water Balance** (main top-down water balance)
- **Performance Indicators** (key PI's from top-down water balance)

3.4.8.1 System Data Form

The system data form is used to collect the basic system information for the water utility being analyzed. The forms of system data are water undertaken, system pressure, mains and connections. For all forms providing data and completing before running. The length of mains, associate pressure and number of connections in the distribution as well as the average length of pipe from the property boundary to the water meter are also calculated and putting into the software in order to calculate Unavoidable Annual Real Losses (UARL) which forms part of the PI calculations.

3.4.8.2 Water Balance Form

The water balance form is the key form in Aqua Lite and is the main area of the model where the top-down water balance is undertaken. The Aqua Lite model allows investigating the real losses in greater detail than many other models. The component of water balance is discussed in details as below.

I. Billed Metered Consumption

When clicking on the detail tab for the Billed Metered Consumption on the main water balance, a new form appears in which the user can supply the relevant information for the water that has been billed and metered and filled data including domestic consumers and non-domestic consumers.

II. Billed Unmetered Consumption

When clicking on the detail tab for the Billed Unmetered Consumption on the main water balance, a new form appears in which the user can supply the relevant information for the water that has been billed but was not metered. This is often appropriate in areas where water is charged on a fixed monthly charge and not based on metered consumption and filled for domestic consumers and non-domestic consumers.

III. Unbilled Metered Consumption

This is included to fill of record users such as firefighting and water used in parks and public gardens where the water is measured but no bill is sent to the municipality.

IV. Unbilled Unmetered Consumption

The Unbilled Unmetered Consumption form is basically the form where the water utility estimates the amount of water that is used officially but is neither metered nor billed. Ideally this form of water use should be relatively small.

V. Unauthorised Consumption

In many parts of the world the Unauthorised Consumption will be negligible and the values entered into the form should be small. In other parts of the world, however, theft of water is a major issue and can be a significant portion of the overall water balance.

VI. Customer Meter Inaccuracies

The Customer Meter Inaccuracies form is slightly different to the previous forms in the respect that the user does not supply a quantity of water in the form but rather the percentage under registration of the meters. In most water supply systems the customer meters are replaced on a regular basis with the result that they may be relatively accurate and the under registration may be only a percent or two.

VII. Performance Indicators Form

The Performance Indicators Form is the final form in Aqua Lite model and made up of 4 main sections namely:

- ✓ The basic input data used to calculate the Unavoidable Annual Real Losses
- ✓ The calculation of the Unavoidable Annual Real Losses
- ✓ The cost components for the water

The basic input data used to calculate the Unavoidable Annual Real Losses includes:

- Average pipe length from street edge to meter;
- Length of mains;
- Length of distributions
- Number of service connections;
- Average operating pressure of system;
- Number of accounts

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Existing Water Supply Coverage

The water supply coverage of the sub city has been evaluated based on the average per capita consumption and level of connection per family. The average per capita consumption has been derived from the yearly consumption of each customer that has been aggregated from the individual customer water meters. Number of population as forecasted to the year 2015, 2016 and 2017 has been used to evaluate the average per capita consumption.

Access to existing water supply coverage may be evaluated using the amount of water consumed and by level of connection per family for evaluating the amount of water consumption; the annual water consumption is converted to average daily per capita consumption using the population data of sub city and customer data. Besides population distribution by mode of service has been also used as elaborated below.

4.1.1 Average Daily per Capita Consumption

The level of water consumed for domestic and non-domestic purpose has been aggregated to the sub city so as to analyses the distribution of the water coverage among different localities. Evaluating the domestic and non-domestic water supply coverage using volume of consumption may not allow realizing the distribution comparison among the sub city. For this reason the annual consumption data has been converted to average daily per capita consumption using the forecasting of population and individual customer bill data of Akaki branch starting from 2015 up to 2017 year. To obtain the exact figure of water consumption, it was required to compile customers billing data. Starting from 2015 up to 2017 years the compile customers billing data of domestic, non-domestic and fountain data were described in Table 4.1 including supplied water by truck for different construction site like condominium construction site and for the place of shortage water.

Table4. 1 Water production and consumption of Akaki Kality (2015-2017)

Year	Production (m^3/year)	Total Billed Data /Consumption(m^3/year)				Total Population	Consumption L/person/day
		Domestic	Non-domestic	By Trunk	Total		
2015	9368078.46	2362254	3704302	22695	6089251	243712	26.56
2016	10289184.62	2979164	3688676	20130	6687970	262168	31.13
2017	11260256.92	3656263	3643869	19035	7319167	273141	35.72

Using water production and total water consumption data obtaining from customer billed data and water supply by trunk, the existing water supply coverage of Akaki Kality sub city is access by using average Daily per Capita Consumption for three years were calculated.

As shown on the Table 4.1 the distribution of average domestic and non-domestic water supply coverage of the sub city in the year 2017 is found to be 35.72 l/capital/day by using Equation3.1. This average per capita consumption is very low while compared with the country standard used for design purpose (40 to 100 l/capita/day) as per EBCS 10.

4.1.2 Level of Connection per Family

The total numbers of connection or water meter within the sub city are about 46648 among those, 40427 are for domestic use until this data was compiled. In order to compare the distribution of the water connection for the sub cities, the total numbers of connection per Woredas are converted to connection per family using the population data of the sub cities .By using average family size of 5.5, the average number of connection per family is calculating as express in Equation 3.2.

Table4. 2 Level of domestic water supply coverage per family

Year	Total population	Average family size	Total number of domestic connection	Level of Connection
2015	216538	5.5	21520	0.49
2016	221759	5.5	24879	0.55
2017	227182	5.5	33582	0.73

As shown in the above Table 4.2, the average connection per family for the sub city is found to be 0.59. This implies that at average two families or eleven people are sharing one connection or water tap in Akaki Kality sub city.

4.1.3 Distribution of Water Supply Coverage

In this section the distribution of the consumption in relation to number of population is discussed. In areas where water supply coverage is sufficient, volume of domestics water consumption is expected to be linear related to the level connection. Areas having better level of connection are expected to consume more water as they can easily get it within their building or compound.

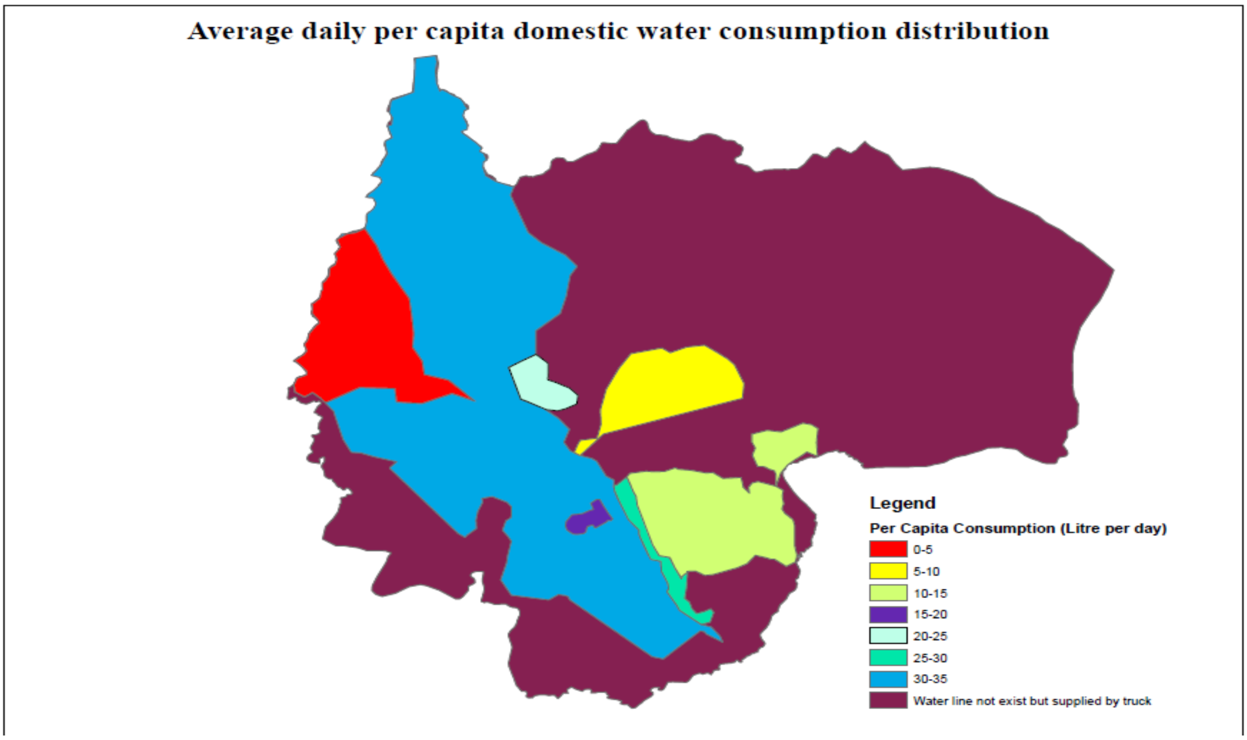


Figure4. 1 Distribution of average daily per capita consumption

As shown on the Figure 4.1 the distribution of average water supply coverage of the sub city is low especially in new Woredas like Woreda 9, 10 and 12. For those three Woredas, water is distributed by water trunk and public tap.

4.1.3.1 Correlation between Population and Billed Consumption

It is necessary to evaluate consumption with population. This has been evaluated using the correlation between the water billed consumption and number of population. Plotting water consumption by number of population graphically illustrates R-squared values for regression models are shown in Figure 4.2.

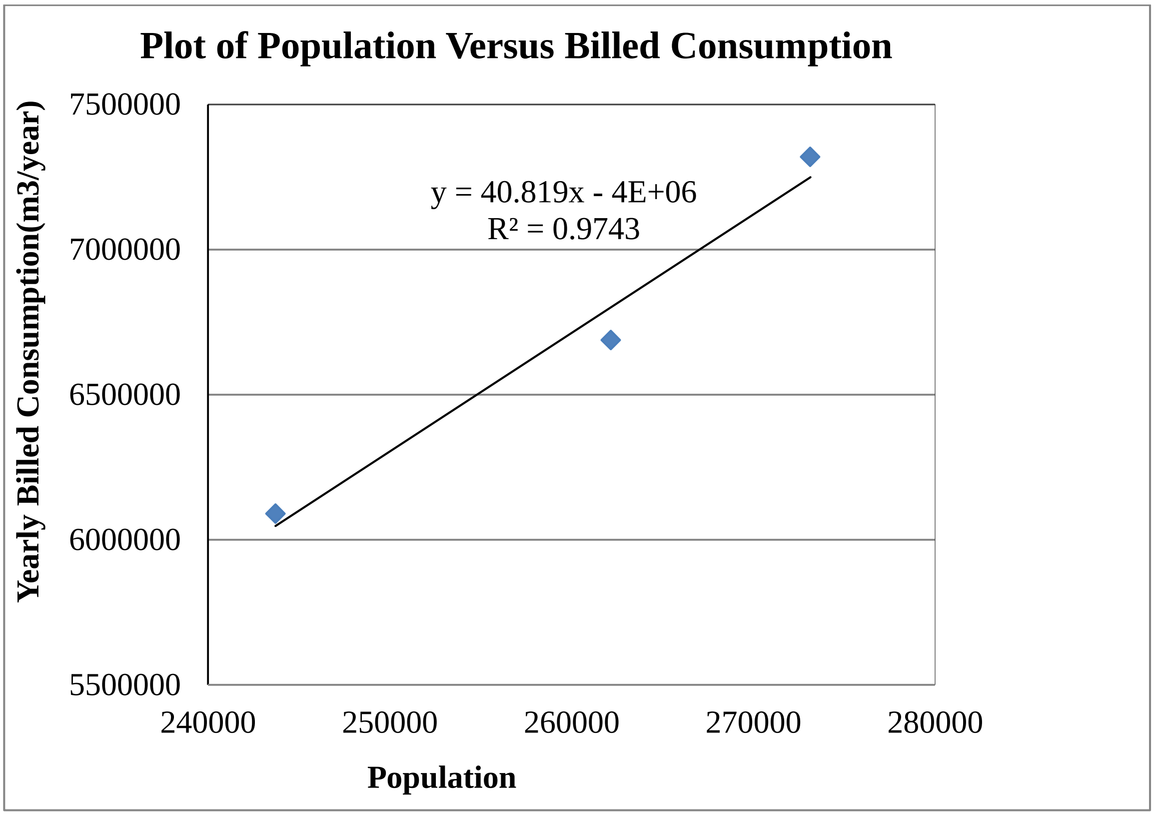


Figure4. 2 Scatter plot for volume of water consumption and number of population

As shown in the above Figure 4.2 the coefficient of determination (R^2) is 0.97, which indicates that the regression model accounts for 97% of water consumption is explained by population size.

4.2 Water Loss Analysis

. The total annual water produced and distributed to the distribution system and the water billed that was aggregated from the individual customer meter readings were used to quantify the total water loss for the sub city. All the water consumptions in the sub city were metered except very few like water supplies by trunk, for firefighting use and water used by the water authority itself. As referring the report of AAWSA in Akaki branch, the annual water consumed for firefighting and that of consumed by the water authority itself was estimated to be accounted only 0.1% of the total annual water production. As the authorized non-metered consumption are insignificant while compared with the total water production.

The production figures are taken from the water meter installed at the place where the production of water gone other sub city which produces from Akaki Well and Spring and the consumption is read from the water meters installed for the customers and public fountains. The three years actual production and consumption figures obtained from the sub city water supply service is presented in Figure 4.3 by using Equation 3.3.

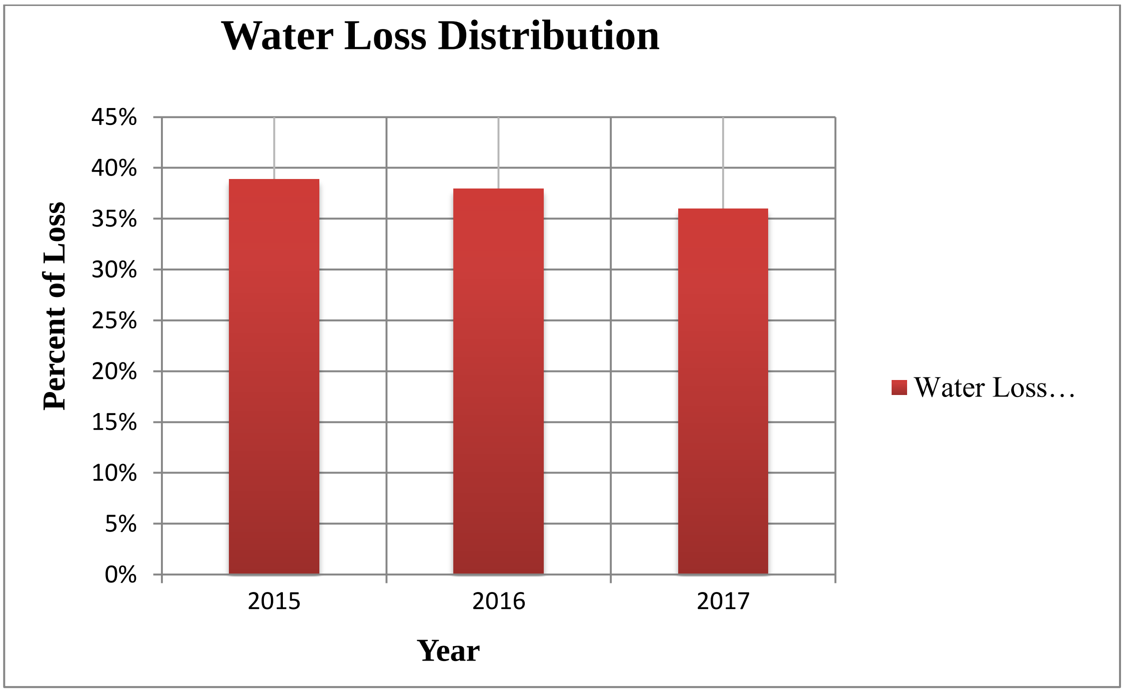


Figure4. 3 Annual water losses of the sub city

As can be seen in the above Figure 4.3 the total annual water loss of the sub city is decreased from year to year at the end of the year 2017. The annual water produced and distributed to the system within specified year was 11436198.44m^3 and annual water loss as derived using the above expression was 4117031.44m^3 which account to 36.42% of the total production. Thus unaccounted for water is already on the higher side for the sub city of Akaki Kality which its size is expanded day to day and increasing population due to highly construction of ceondominiyem in thus sub city. So decreasing the existing losses must be considered as part of the immediate rehabilitation plan of the Addis Ababa water and sewerage authority.

Water loss is usually expressed in terms of percentage (UFW), loss per kilometer length of main pipes and loss per properties or number of connections. The total water loss has been evaluated based on the three measurement approaches as explained here under.

4.2.1 Total Water Loss Expressed as Percentage (UFW)

The total annual water produced and distributed to the system within the specified year (2017) has been 11436198.44m^3 and the annual total water loss as derived using the above expression was 4117031.44m^3 that accounts to 36.42 % of the total water production. Taking the average tariff of water in the Addis Ababa city as1.95 birr/m^3, the water loss is estimated to be 8.03 million birr every year. However, the real loss is beyond this as the water tariffs like other developing countries are usually subsidized.

4.2.2 Water Loss Expressed as per Number of Connection

Water loss expressed as a percentage could be an appropriate means to show the extent of the loss within a given environment, but it is not a good indicator for comparing the losses from one area to another. According to some literatures, comparison of water loss between different areas is recommended to be done using the water loss per service connection per day. Taking the total number of connection in the sub city is 11,014km and the water loss per connection for the similar duration was calculated as 137.72 liter/connection /day. This figure shows as litters per service connection per day increase water losses also increases.

4.2.3 Water Loss Expressed as per Length of Pipes

Water loss expressed as per kilometer length of main pipes is also used as indicator to compare water loss. This indicator is usually recommended for non- densely populated areas like Kilinto, Koye Face, Tullu Dimtu, etc. The total length of pipes of size 50mm and above of the entire sub city is 1,681 kilometers out of which nearly 679 kilometers were categorized as main pipes according to the classification of AAWSA. Nevertheless, as there are some pipes that their diameter not clearly identified, all the pipes greater or equal to 50 mm in diameter have been used to evaluate the water loss per length of pipes.

Using the total pipe length of the entire sub city, the water loss per kilometer length of main pipes was calculated as 38.14 m3/ km/day depending on total water loss and total pipe length. This figure shows that as length of the pipe increases the amount of water losses per day increases.

4.2.4 Determination of Unavoidable Annual Real Loss (UARL)

This category represents the allowable volume of real losses from the system, which estimates a volume of leaks that are undetectable or would be uneconomical to repair during the year. This can help to evaluate the feasibility of real loss minimization (provides better understanding of real loss components).

Considerable work was undertaken to assess the minimum level of leakage for any system (Lambert et al, 2008) and after careful analysis a relatively simple and using the developed equation 3.4, the value of UARL is 1115726.68m^3/year. This value is represents the unavoidable annual real losses (UARA) is the lowest technically achievable volume of real losses which is 4117031.44 of cubic meter at current operating pressure.

4.2.5 Calculating Infrastructure Leakage Index

The infrastructure leakage index (ILI) indicator is a new indicator of water supply systems expressing the technical condition of the system from the point of view of water loss. This indicator is proposed and recommended by the international water association IWA (Lambert, 2004). As the operating records kept by the operator do not make it possible to determine the actual real losses (RL) individually for each pressure zone.

Based on equation 3.5 the infrastructure leakage index for the Akaki Kality distribution system is calculated as 3.69 and this shows us that the current annual real losses are assessed as being around four times as high as the unavoidable annual real losses for the system.

4.3 Evaluating Possible Causes of the Water Loss

There are several reasons for the high level of water loss generally in Addis Ababa and particularly in Akaki Kality sub city. These factors are given below, and some advisory solutions were briefly proposed in next sections.

4.3.1 Age of Pipe Network

Pipe age is one of the factors that affects the magnitude of the loss specially that of physical loss. Aged pipes are more likely having more water loss through leakage than newly installed pipes. It is estimated that nearly more than 50% of the pipe network in the Addis Ababa city was laid over 25 years ago. The main duties which made more than half a month is checking of each customer (door to door water connection) by sounding rod .In this time, it was found so many invisible & visible leakages both on the private connection & also on the main line.

Totally there was identified 9135m service lines, (682customer connections) from this it was found 194 leaked connections, most leakages were easily detectable and the rest were not maintainable because of its long service age. So it was decided to change by new line.

Figure4. 4 Example of water loss due to age of pipe

4.3.2 Poor Maintenance of Networks

In some places like expansion areas including Alem Bank, Tullu Dimtu, Koye, Salo, Furi, etc., water authorities has performed a maintenance program for distribution system, and in recent years more than50% of network system was replaced in the expansion areas. For partial Woredas, but in all sub city poor maintenance of network and poor man power management for maintenance, it is so difficult to find financial support to renew the water distribution system. Thus, the lack of finance to proper materials and poor construction resulted in increased leakage in the system.

Figure4. 5 Improper connected of pipe

4.3.3 Customer Side Leakage

Many water institutions do not give enough attention for water losses caused as a result of metering errors but it has a considerable impact unless due attention is given like to that of the pipe networks. As per the feedback from the local experts, until recently the water authority was not checking the customer meters by itself unless the customers apply for checkup. However, customers apply most probably when the problem were over-registration rather than under registration. Generally as discussed in the previous section the total water loss of water due to meter inaccuracies accounts to 93,057.42m^3/year and this cover 16.8% of the total water loss of the distribution system.

Figure4. 6Water losses due to carless of customer

4.3.4 Illegal Connections

There are a significant number of illegal users of water within distribution system in Addis Ababa City especially in the expansion areas or construction areas. The number of households who do not pay water rates but receive water from its distribution system is not known by the Authority. As a consequence, they contribute significantly to apparent losses and revenue loss to the water authority. These connections are often poorly laid just a few meters below the surface and will break easily resulting in real losses taking placed in the form of leakage. Illegal connections are therefore of significant concern of water utilities.

4.3.5During Construction of Utility

As we know most area of Akaki Kality sub city is the expansion and industry area. In this sub city there are many construction of utility like condominium house in different sites, roads, sewer line, Telecommunication line, etc. were worked from time to time. During those utility were constructed water line including mail line and customer line were broken and water lose is highly occurred up to the authority technician came and maintain. As it was tried to observe, any contractor or the client of those utility don not care about water line during excavation. Even though when broken the water line and water is highly lose do not report for the authority. So AAWSA were significantly concern this issue and communicate with the owner of those utility before starting excavation or construction and also ready to stand by during excavation on the site especially during excavation of main and secondary of sewer line at different sites.

Figure4. 7 Water during losses construction of sewer line

Figure4. 8Water losses during construction of Telecommunication line

4.4 Possible Solution to reduce water loss and leakage

Knowing the magnitude and the spatial distribution of the loss greatly helps to intervene giving priority to those areas with higher magnitude of loss with regard to the leakage index usually fixed based on local condition. Nevertheless identification is not by itself an end in reducing the water loss. Identifying the causes of the losses might help where to focus with probably limited resources that the city is having. This study somehow gave an indication that the predominant causes of the water loss in the city is leakage and losses due to meter errors. Once the spatial distribution and the characteristics of the loss are identified; it is possible to see alternative solutions to reduce the water loss. Therefore, an appropriate long and short term strategy is necessary.

As shortage of water is a crucial problem in the city, great attention is given to the issue of water loss by the water authority. Furthermore, AAWSA were must create a new department of research and water demand has been established that one of its responsibilities is to reduce water loss. As per the information found from the experts of the AAWSA, the newly established department is at its start of the work organizing data from different sections.

Generally the following may be considered to be possible solution to be taken to reduce water loss and leakage in a distribution system.

4.4.1 Updating network data

Availability of correct and current data is an important step for evaluating a water loss and take measure accordingly to reduce the loss. Unless appropriate data is available at different hierarchies of the network system, it will be difficult to identify and locate the areas that are in a bad condition. Record-keeping is an essential part of water network management, and is also the base for GIS. Supply zone and district meter areas (DMAs) records should relate to both physical records and records for leakage analysis. If network records are poor, a network survey is essential before zoning and DMA design can take place, and for accurate leak detection and location to be carried out.

AAWSA has done a lot with this aspect that most of the network records like the pipe sizes, material types and years of installation are collected and stored in AutoCAD format. This is an important step for managing the network as well as monitoring the water loss, but other records like maintenance and pressure records need also integrated with the network.

4.4.2 Improving billing system and meter readings

Improving a billing system is one step forward for improving the overall demand management of the city and helps to a great extent to better evaluate the water balance and water loss. The most important part of determining how much water is being lost in a system is to accurately quantify the volume of water which is entering that system. Metering of input volumes and inflows into zone distribution systems is essential for water balance calculations. But Customer meters also require careful management of water loss if representative and significant results are to be obtained.

Billing system can be reviewed and updated for the integrity and quality of the data. The location and the historical records like ages of the meter, periods of calibration, etc. need also be integrated with the billing systems.

4.4.3 Calibration and replacement of customer meters

One of the main causes for the water loss is the under-recording of customer meters. The usage of poor material quality also holds true for the customer meters. Unless meters are regularly calibrated and those not functioning well are either maintained or replaced the water loss reduction programmed will not be effective. Until recently, the water authority was checking the customer meters only if it is requested by the customers themselves, but this might only help the customer not to pay more as such requests are usually for over registration. Therefore systematic checkup of the customer meters is important not only to identify the magnitude of the loss but also to maintain and replace when necessary.

4.4.4 Proper maintenance and renewal

One of the major causes for the increase of water loss is the usage of poor quality materials and poor workmanship. In spite of the many pipe networks in the sub city seem to have younger ages, the loss found from the analysis reaches up to 40% of the production. The main reason for this might be the usage of poor quality of material and poor workmanship. Therefore care should be taken while maintaining existing networks and installation of new ones. While rehabilitation of any mains is planned, due attention should be given to maintain as well the service connections fed from the mains.

Replacing an old water main with a new installation will undoubtedly reduce on the main. Most leakage occurs on service connections and, unless the service connections are also renewed, the benefit may not be a great as the first estimated (Farley and Trow, 2003).

4.4.5 Improving organizational management and provision of training

For an effective management of water supply service in general and water loss and leakage in particular, water supply providing institutions must have an appropriate organizational management. The organizational aspect related to the water loss management is well addressed in the organizational structure of AAWSA, but lack of qualified and experienced personnel is the major problem of the country in general and AAWSA in particular. Capable management and technical staff are paramount take training regarding to water loss management in order to achieve better performance. Offering a continuous theoretical and practical training based on the need is also important. Due to the complex nature of water loss and leakage commitment of staffs at all level is also very important.

Effective leakage management requires an input from a number of different personnel and unless, they are all committed, the implementation of any water loss reduction programme will not be efficient, it may then be difficult to maintain the infrastructure which has led to lower leakage levels (Farley and Trow, 2003).

4.4.6 Establishing of Information Disk

As observed during field study, water was loss at different place by different cases as mentioned in previous section in the causes of water loss. Those water loss were continues to loss for one day or two day some time above until the authority technician (workmanship) saw. So in order to arrive automatically when water is loss and make a possible solution AAWSA has established a free telephone service that can support to get information from the community in case of leakage and breakage of pipes immediately.

4.5 Population Forecasting

In order to forecast the current population (2017) and future population of the study area based on last population census report population and housing census report of 2007 which was prepared by Ethiopian Central Statistical . But for future projection of population up to 2037, the growth rate is not proposed for 2030 -2035 and 2035 -2040 by SCA. For those intervals the growth rates forecasting by plotting the graph and using the regriation equation which is described as below.

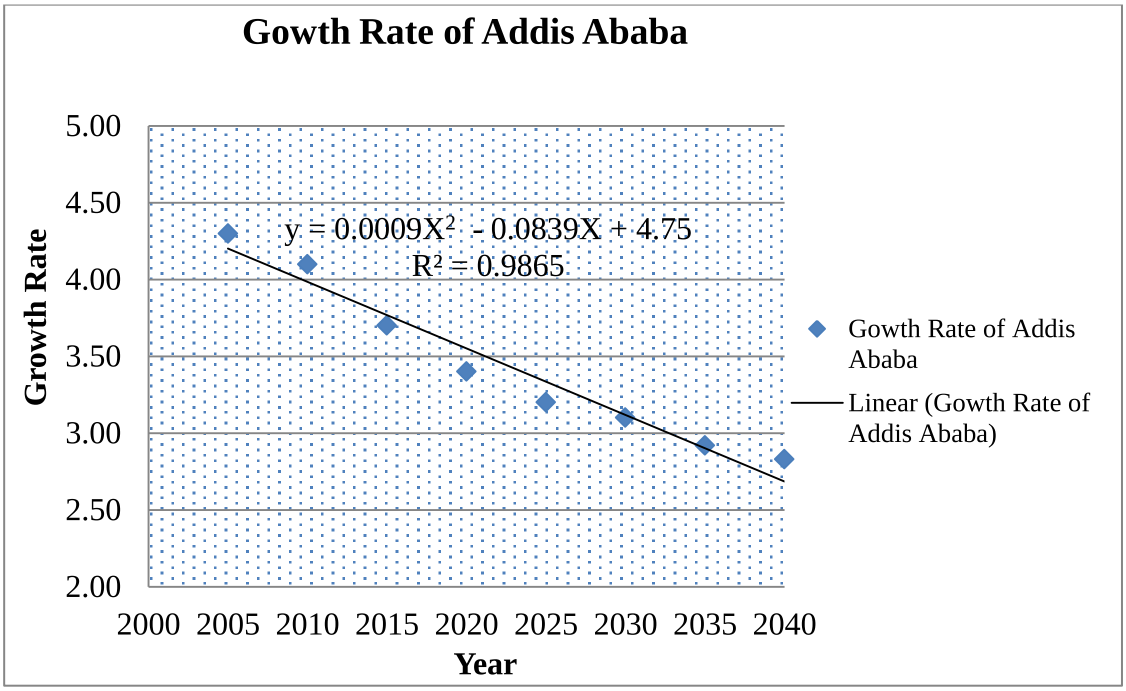


Figure4. 9 Proposed growth rates

From this expression the above graph function is $Y=0.0009\ X^2 - 0.0839X + 4.75$ and the factor $R^2 = 0.9865$ that means Y is from the graph represent the growth rate and X is represent the year and the growth rate for 2030 – 2035 and 2035 -2040 are 2.92 and 2.83 respectively.

Applying the growth rate in exponential population forecasting method, the population of Akaki Kality is projected up to year 2037 and is presented in Appendix-B.

4.6 Projected Demand (2017 – 2037)

The current estimation of water use by entire population required to review a set of various data. Water production data along with present and future population data were repeatedly reviewed.

Accordingly, the two mentioned data were primarily used for water demand analysis. Prior to assigning project water demand, it was required to establish average use of water per person. Per capita water demand was taken as average water use. Maximum water use and minimum water use usually related to average water use by multiplication of peaking factors and adjustment factor for climate and social change. Results of water demand projection are shown in Table 4.3 as follows and the details are attached in appendix B within projection of population.

Table4. 3 Summarizing current and projected water demand in Akaki Kality

Year	Projected Population	Projected Water Demand (MDD)
2017	254675	17901264.64
2018	263483	18520372.84
2019	272595	19160892.65
2020	282023	19823564.59
2021	283720	22394682.77
2022	292946	22979839.82
2023	302472	23727086.88
2024	312307	24498632.56
2025	322463	25295266.97
2026	326682	28095163.75
2027	336968	27685648.75
2028	347577	28557345.36
2029	358521	29456487.76
2030	369809	30383940.12
2031	365325	30962935.71
2032	376150	31880382.97
2033	387295	32825014.66
2034	398771	33797636.26
2035	410587	34799077.12
2036	411862	36948138.72
2037	423684	38665661.45

4.7 Distribution System Modeling

4.7.1 Model Representation

Frequently system maps are drawn as combination of various system components enclosed in water distribution system. It is common to include; Reservoirs, Tanks, Pipes, Pumps and Valves as much as possible and the resulting sketch fairly represent the actual water network. With little difference the real water distribution system represented as combination of nodes and links. Junctions, reservoirs and tanks are usually referred as nodes. Pipes pump and valves are categorized as links. Figure 4.6 below illustrates layout of Akaki Kality distribution system. The sketch was extracted from Addis Ababa water distribution system map and represented in the model according to available drawing options. Model system is numerically summarizes the elements which presented in Table 4.4.

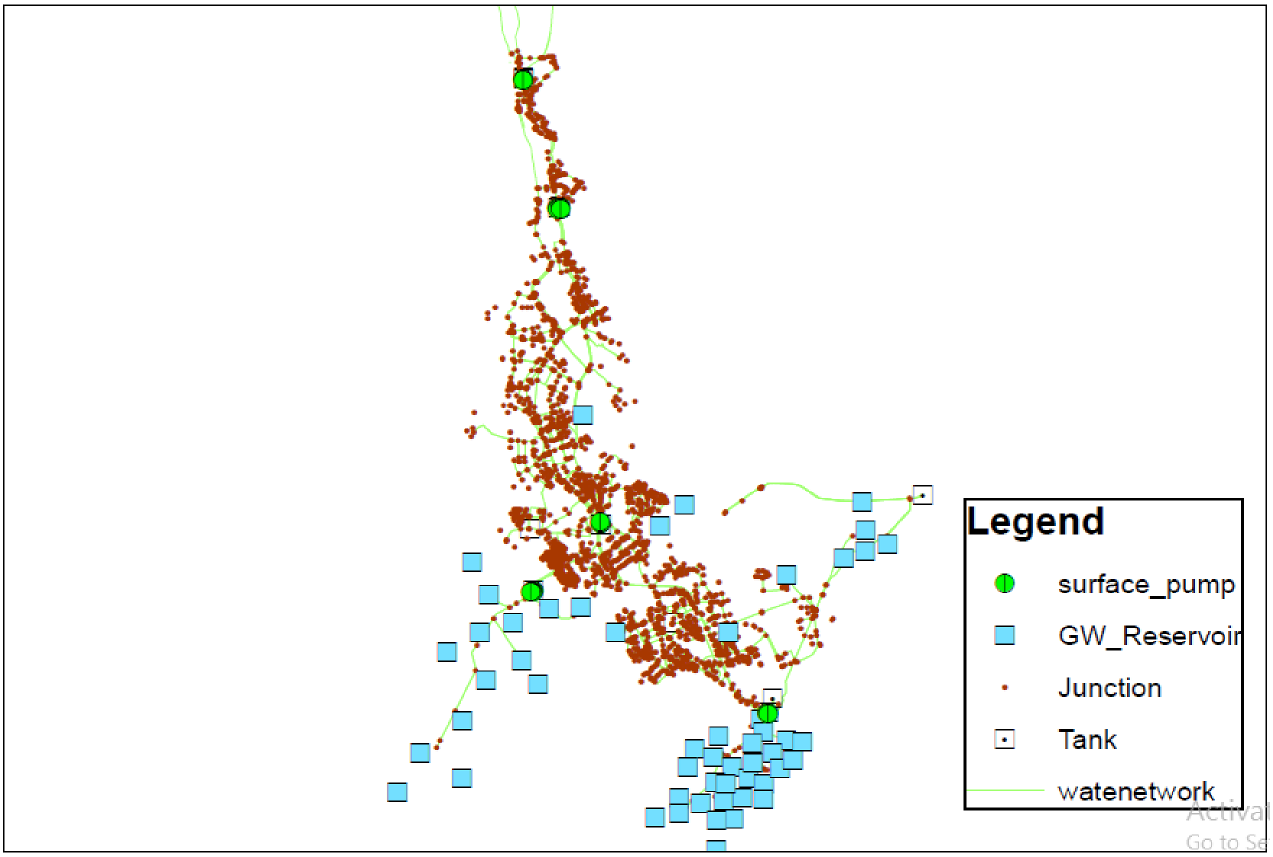


Figure4. 10 Modeling of the system

Source: AAWSA Akaki Kality distribution networks, 2017

Table4. 4 Summary of system elements

System components	Number
Reservoirs(Borehole)	53
Tanks	10
Pumps	5
Pipes	1646
Junction	1267

4.7.2 Model Calibration and Validation

Model calibration is the process of comparing the results of model simulation to actual field data and making corrections and adjustments to the model in order to achieve close agreement between models predicted values and field measurements. Typical comparison values include pressures, flow rates and service reservoir water levels. Model parameters that may require correction during the calibration process include system connectivity, node ground elevations, control valve settings, pump characteristics. Estimated model parameter values that may require adjustment include pipe roughness coefficients and nodal demand allocation and peak factors.

4.7.2.1 Hydraulics Calibration and Validation

The credibility of a model is merely evident if a model result precisely reflects observed field values. Thus, to have a confidence on model result it needs to calibrate a model. The calibrations have been carried for the J-793, J-826, J-63, J-427,J-590, J-675,J-724, J-772, J-901, J-969, J-134 and J-133 set closed and base scenarios, for the model validation. An effort to perform hydraulic network model calibration and validation for this case study is presented as follows.

Twelve representative sample measurements (twelve data sets observed data and twelve data sets from simulated) the water main spread throughout the study area have been selected for the calibration. It was difficult to take measurement at a direct connection to the water main nodes, due to size of pressure gauge available only in this junction.

As a result, 100% of the field test measurements were within ± 2 m, showing an acceptable level of pressure calibration criteria in chapter three (methodology part). The comparisons of model simulated and field test are described below in Table 4.5 and Figure 4.6. Calibrations have been carried on the base scenarios within the acceptable level. Hence, the model is valid for the scenarios.

Table4. 5 Comparison of simulated pressure result with field measured data

S. No	Sample junction	X	Y	Elevation (m)	Observed pressure (m)	Simulated pressure (m)	Difference pressure error(m)	Time from start (hr)
1	J-798	474300	140000	2152	39	41.91	(2.91)	8:00-12:00 (early mid noon) 2:00-6:00 (afternoon) 8:00-12:00 (early midnight) 2:00-4:00 (early morning)
2	J-826	473875	984339	2157	35	40.05	(5.05)	
3	J-63	475000	981377	2096	24	27.32	(3.32)	
4	J-427	473505	985623	2171	35	36.69	(1.69)	
5	J-590	477331	979734	2073	12	18.54	(6.54)	
6	J-675	473936	987034	2171	55	57.18	(2.18)	
7	J-724	475589	983994	2106	39	40.47	(1.47)	
8	J-772	476405	982873	2149	18	19.50	(1.50)	
9	J-901	473602	982625	2144	51	55.39	(4.39)	
10	J-968	475240	987299	2160	19	21.94	(2.94)	
11	J-134	479879	980197	2150	80	82.79	(2.79)	
12	J-133	474487	985447	2143	32	37.82	(5.82)	
Average					36.58		(3.38)	

Figure 4.6 below is illustrating plots of observed versus simulated values along with minimum and maximum difference between them. The regression model accounts for 95% of the variance this shows that there is a strong correlation between observed and simulated values.

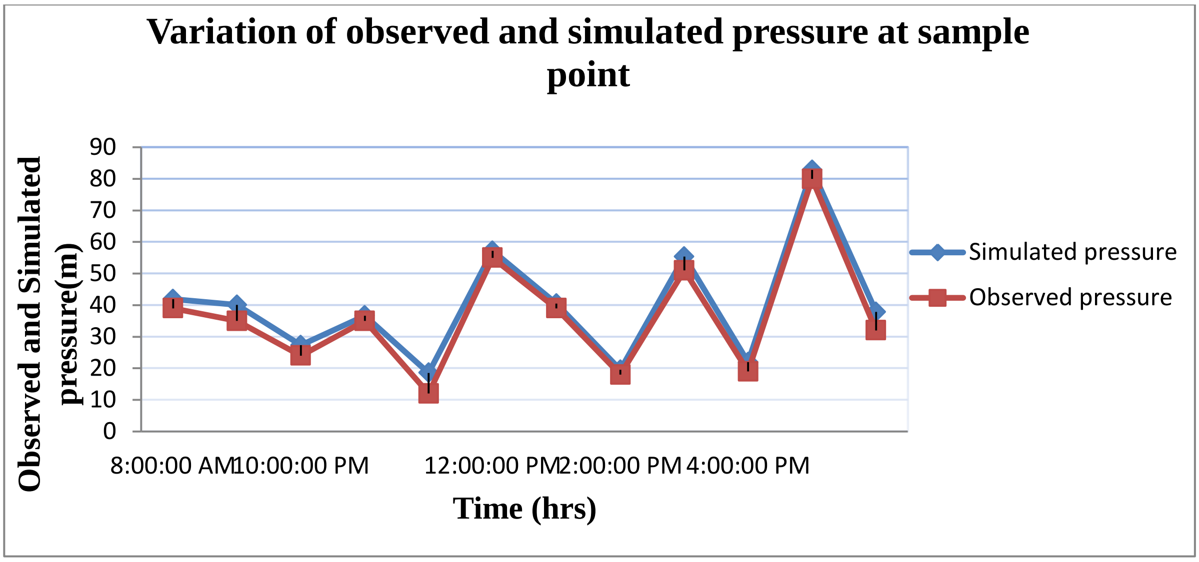


Figure4. 11 Actual and simulated pressure at samples junction

4.7.3 Simulation Results

Single period and extended period simulation were subsequently performed. It was required to run single period simulation at the beginning of the simulation as to observe the model under snap shot situation. In line with this running, single performing preliminary model calibration. However, it should not be used for network assessment as water distribution system is likely to experience variations. Hence, only extended period simulation was exclusively used for entire model calibration and model assessment effort.

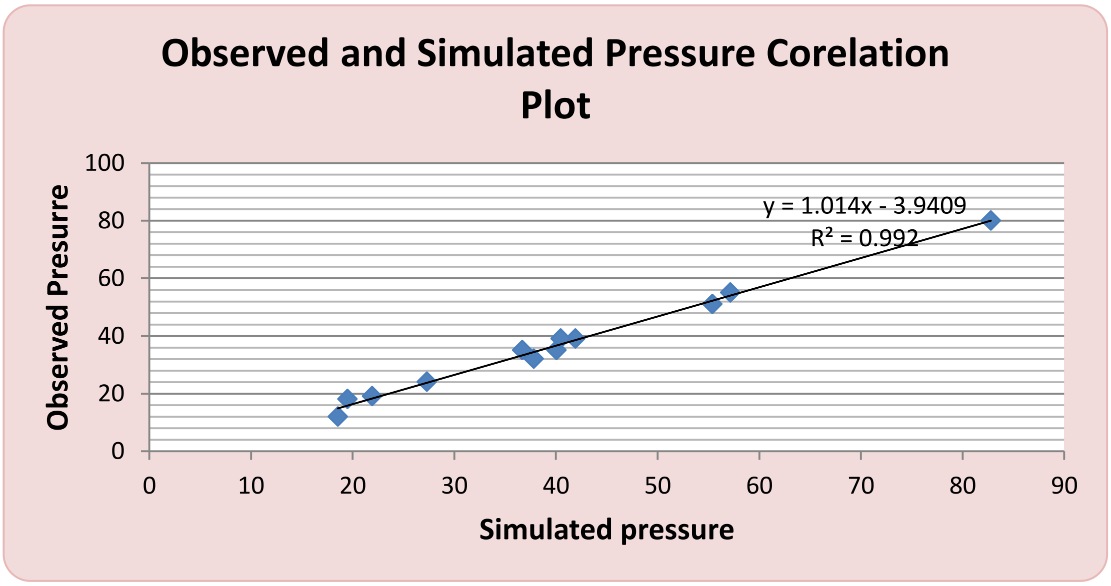


Figure4. 12 Correlation between observed and simulated pressure parameters

From Figure 4.7, the coefficient of determination (R^2) value was 0.992 and it indicates that observed and simulated relation is strongly as values tend to 1. Ideally all the points should align themselves on this line; meaning that all observed pressures would be equal to the computed pressures, giving a correlation coefficient of 1 that is the best correlation between observed and simulated.

4.7.3.1 Pressure

Pressure in water distribution system has to be maintained optimum; as to efficiently make water available to each demand category including at instances of firefighting (with drawl period) and as to reduce leakage as well as pipe breakage across the system. The former one is frequently achieved in setting minimum pressure to be maintained at each junction. The later one is achieved differently in setting maximum allowable pressure to be maintained in the system.

According to (Swamee et al., 2014) the minimum design nodal pressures are prescribed to discharge design flows onto the properties. It is based on population served, types of dwellings in the area, and firefighting requirements. The general consideration is that the water should reach up to the upper stories of low-rise buildings in sufficient quality and pressure, considering firefighting requirements. In case of high-rise buildings, booster pumps are installed in the water supply system to water for the pressure head requirements. With these considerations, various codes recommend minimum ranging from 8 m to 22 m for residential areas. Similarly, (Jeffrey et al., 2009)recommend;

1. Minimum pressures at peak hour demand: sufficient to serve the highest supply point in the network. Typically a mains pressure of not less than 15 to 20 m would be required to serve buildings up to three stores high. Higher pressures may be necessary in some areas where there are significant numbers of dwellings exceeding three-store height; but high rise buildings are normally required to have their own boosted supply.
2. Maximum static pressures during low demand periods: typically at night, should be as low as practicable to minimize leakage. For flat areas a maximum static pressure in the range 30 to 45 m is desirable.

For the city of Addis Ababa, particularly Akaki Kality sub city is using an operating pressure which ranges from 15m to 80m. However, there was no defined maximum and minimum pressure ranges set by the office. Therefore, literature based recommendation for optimum operating pressure was used to assess system hydraulic performance.

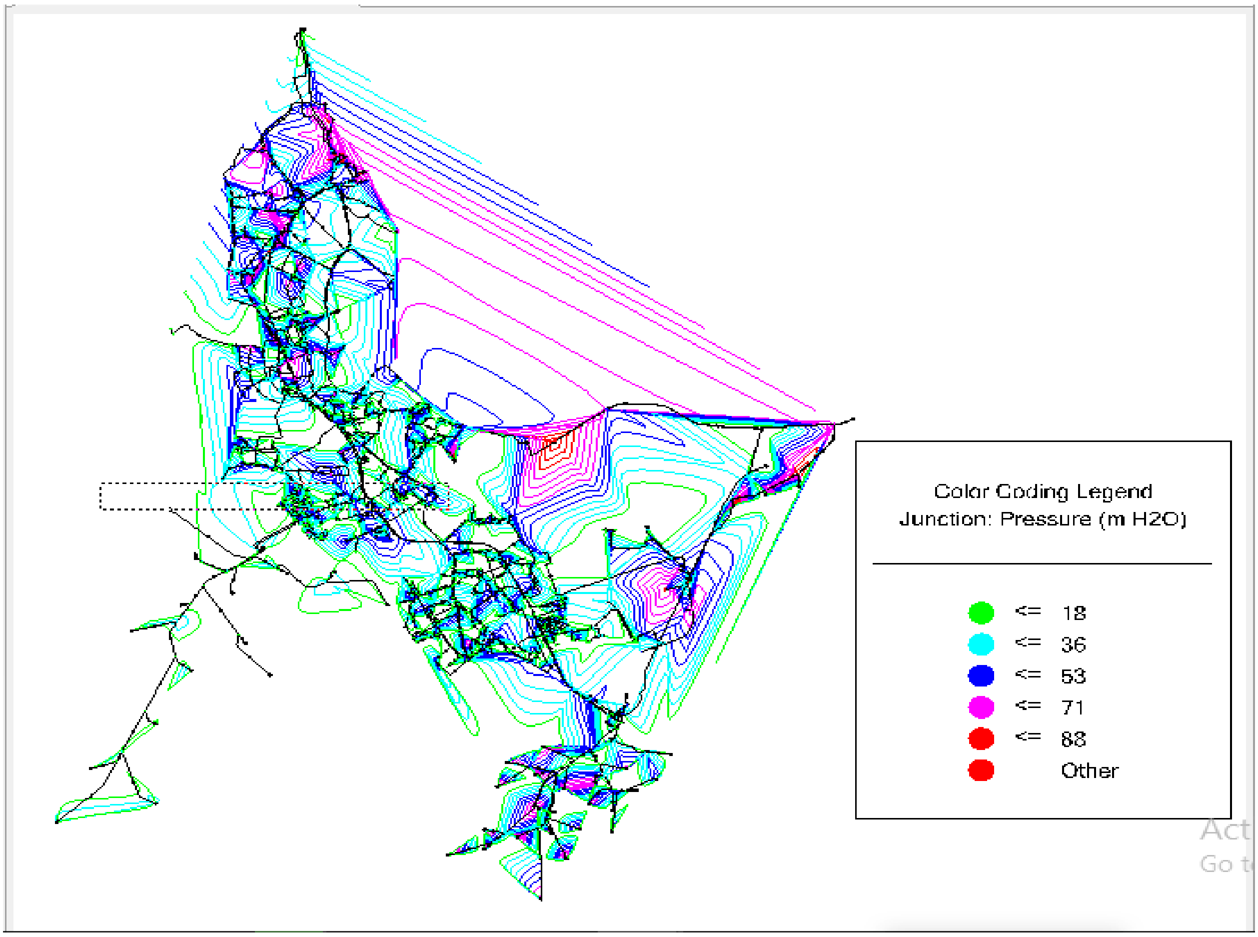


Figure4. 13 Pressure distribution plot peak hour flow

As shown in the Figure 4.8 there are extreme high pressure throughout the system mainly due to the topography of the area and the elevation of the distribution reservoir. In few instances nodes positioned in left and right side of network are susceptible to low pressure. Whereas majority of nodes located in central networks are relative perfect loop region receive optimum pressure which doesn't violate minimum or maximum allowable pressure range.

4.7.3.2 Velocity Distribution in Actual Pipe

Velocity of water flow in a pipe is also one of the important parameters in hydraulic modeling performance evaluation of the efficiency of water supply distribution and transmission line. Velocity distribution is also varying with demand pattern changes. At the peak hour demand the values are different as compare to minimum consumption hour. The water supply system network velocity during peak hour demand is presented in the Figure 4.9 below.

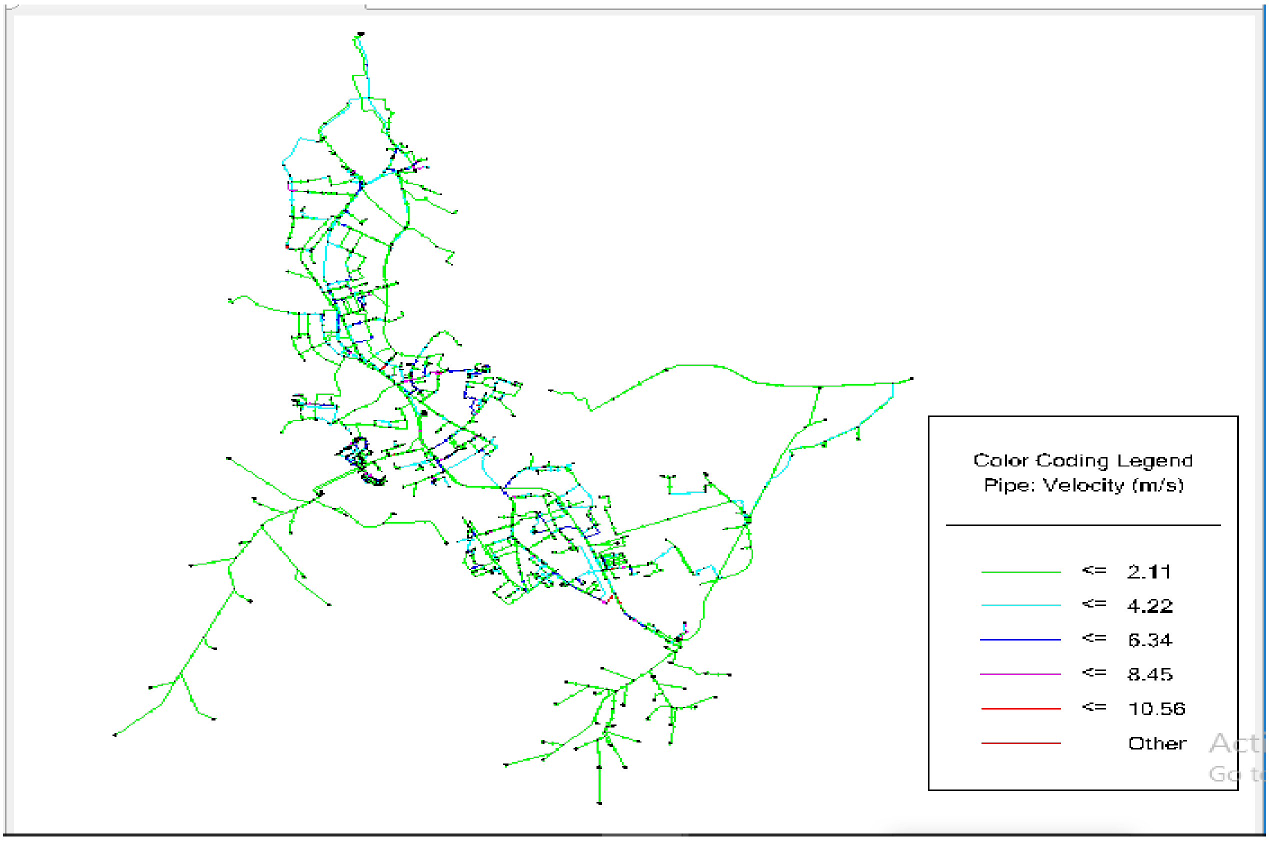


Figure4. 14 Velocity in the undersized and oversized at peak consumption peak hour flow

4.7 Implementation of Pilot District Metered Areas.

Five pilot DMA areas have been done by supporting AAWSA Akaki office technician and daily labor by following the methods which described in methodology part and comprising in most cases 400-1,400 customers and having one or two water supply inlets. They were determined on the basis of recommendations by the Branch Offices which were made after guidelines were provided during meetings that took place. The five pilot DMA areas were subsequently carried out field inspections of all the DMAs.

The activities constituted stage of the required DMA preparation and at the time of preparation of the Pilot, demand survey results were available for the all DMAs. These activities had to be carried out as far as possible while Active Leakage Control was taking place and the activity for a period of four months starting on September 21, 2017 and finishing on January 24, 2018 after having surveyed a total of five pilot DMAs.

Table4. 6 Time table of activity implementation for DMA preparation

S. No	DMA	Days of survey in total (including follow up report)	Dates of survey(date-month)
1	Salo Addis Sefer, DMA1	13	24-9,25-9, 26-9,29-9, 30-9, 1-10, 2-10, 20-10, 14-11, 12-110, 11-10, 3-10, 4-10,
2	08 Derartu School, DMA2	11	5-10, 8-10, 12-10, 13-10, 14-10, 18-10, 18-11,17-11,19-11,21-11,27-11
3	Kality KK- Textile Factory, DMA3	7	14-10, 15-10, 17-10, 21-10, 19-11, 24-11, 25-11,
4	Cheralia, DMA4	8	26-10, 12-11, 27-12, 11-12, 13-12, 25-12, 27-12 ,3-1,
5	Akaki, DMA5	8	28-12, 30-12, 2-1, 3-1, 5-1, 12-1, 13-1, 14-1

4.7.2 Summary of the Result

Activity was implemented at the five pilot District Metered Areas established in AAWSA’s network as illustrated in Figure 3.3 and water loss by this technique is calculating using Equation 3.8 and the results are summarized in Table 4.7 and also presented in details in Appendix D.

Table4. 7 Results Summery of Pilot DMA

DMA	Location	Coverage Areas (sk.km)	Water distribution pipe length (m)	Costumer Size	Water Loss in (%)	
					Before action taken	After action taken
DMA1	Salo gora	0.36	6815	765	35.21	20.12
DMA2	woreda 8 around KK textile factory	0.32	3830	443	36.73	22.92
DMA3	Woreda 8 CBE Melka Shane Branch	0.3	3270	567	40.57	33.14
DMA4	wereda 7 around cheralia condominium	0.29	5505	668	35.06	22.99
DMA5	Akaki town	0.52	7970	1388	35.34	23.35
Sum		**1.79**	**27390**	**3831**		

In this all DMA water loss reduces after an action take and averagely from 36.58% to 24.50% and if keep it on in this manner the water saved from loss is 12.08%.

4.8 Quantifying loss using Aqua Lite Water Balance Software

Aqua Lite water balance software is encouraged to calculate all components of Non-Revenue Water, Apparent Losses and Real Losses using the standard annual water balance. Aqua Lite also includes the calculation of the Unavoidable Annual Real Losses as well as the use of the Infrastructure Leakage Index as a key performance indicator.

For the year’s 2017 IWA water balance components are obtained by using data and estimated all components of water losses and the results are summarized in Table 4.8 below and also presented in details in Appendix E.

Table4. 8 Result of Aqua Lite water balance for year 2017

<table>
<tr><td rowspan="7">Total System Input
10620083.00
100%</td><td rowspan="4">Authorized Consumption
7331740
69.04%</td><td rowspan="2">Billed Authorized Consumption
7324195.00
68.97%</td><td>Billed Metered Consumption
7300132.00
68.74%</td><td rowspan="2">Revenue Water
7324195.00
60.19%</td></tr>
<tr><td>Billed Unmetered Consomption
24063.00
0.23%</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption
7545.00
0.07%</td><td>Unbilled Metered Consumption
7200.00
0.07%</td><td rowspan="5">Non- Revenue Water
3295888.00
39.87%</td></tr>
<tr><td>Unbilled Unetered Consumption
345.00
0.00%</td></tr>
<tr><td rowspan="3">Water Losses
3288343.00
0.39.81%</td><td rowspan="2">Apparent Losses
1012675.77
9.54%</td><td>Unauthorized Consumption
850.00
0.01%</td></tr>
<tr><td>Customer Metering Inaccuracing
1011925.77
9.53%</td></tr>
<tr><td colspan="2">Real Losses
2275667.23
31.43%</td></tr>
</table>

As shown on the above Table 4.8, the results of Non-Revenue water by water balance method high levels of NRW (39.87% of System Input Volume) and water losses (39.81% of System Input Volume) have serious impact on AAWSA and action must be taken to reduce those losses by developing different strategies as discussed in part 4.4.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The main objective of the research was to evaluate the water supply coverage and explore the water loss in the water supply distribution system of the Akaki Kality sub city. The analysis is focused on the evaluation of the existing water supply coverage of sub city based on the billed consumption and population of sub city, projection of demand for next 20 years, evaluating the total water loss and exploring the possible causes of the water loss with their remedial measurement.

- ❖ Both the average water supply coverage and the city distribution were evaluated based on the daily per capital consumption and level of connection using the population data of the sub city. The average water supply coverage of the sub city is found to be 59 liter/person/day. This average per capital consumption is lower compare with other developing cities like the southern of Africa.). The average number of connections per family of the city which is equivalent to 29.13% in-house or yard connection, is also far below the African cities' average of 43%.

- ❖ Despite the low water coverage of the city, the total water loss is found to be high; the total water loss was computed by subtracting the consumption (bill data) from the water supplied is 11436198.44 m3 that means 36.42% of the production water in 2017. Three approaches were used to compare the loss among the sub-system (i) the UFW expressed as a percentage, (ii) loss per length of pipes and (iii) loss per connections, comparison using the percentage has reversed the results of the comparison using the loss per length of mains and loss per number of connection. Therefore, even though the total water loss expressed as percentage is an important tool to know the extent of the loss within a given environment, comparison of losses from one location to another using the percentage has limitations as the percentage of loss highly depends on the amount of water produced. This is also the experience of many international comparisons as explained by the international water association (IWA) task forces. Depending on the hierarchy of the network system, both the loss per kilometers length of main pipes (m3/km/day) and loss per connections (liters, connection /day) may be appropriate to measure the loss. The other issue addressed in the analysis was the major factor contributing to high levels of water loss in Akaki Kality which are: age of pipe network, poor maintenance of networks, water scheduling, customer side leakage, illegal connections and during construction of other utility.

This paper has attempted to put forward the current situation of water loss in Addis Ababa in generally. Besides, it proposes appropriate solutions for the reduction and control of water loss.

- ❖ In this study, water demand is forecasting for the sub city up to 2037 years based on service level and level of consumption, i.e. house connection, yard connection, yard shared connection and public taps. The values of service level and per-capita consumption are taken depending CSA data. Besides domestic demand, non-domestic demand will be considered such as industrial, commercial, firefighting and other an accounted factor with appropriate adjustment factor due to socio economic and climate factor.
- ❖ The other issue addressed in the analysis was that of the role of DMA in reduction of NRW which was prepared five pilot areas at different woreda's. The overall objective of DMA is to control Water loss. Water loss control is to analyze how water loss is caused and to formulate and implement action to reduce it to technically and economically acceptable minimum.

This paper has attempted to put forward the current situation of water loss in Addis Ababa. Besides, it proposes appropriate solutions for the reduction and control of water loss. It is hoped that it will be a catalyst for increased and enhanced awareness and implementation of water loss solutions in the city and this conclusion could only be taken as suggestive findings to be a base for further studies.

5.2 Recommendations

To reduce the current situation of water losses in AAWSA in general and in Akaki branch office particularly, as the study undertaken and modeling result the following sets of recommendations are drawn:

- Follow up high consumer of water, leakage detection both on distribution and customer line.
- The proposed replacement and installation of bulk flow meters should be implemented and systematic flow monitoring in the water supply network must be take place.
- The quality of billing data must be improved. This is necessary for the assessment and control of Non-Revenue Water. It should be aimed to use the new billing database developed by the on-going Billing and IT Project for improved processing and checking of billing data.
- Checking the quality of customer metering. The performance of existing meters was found to be unacceptable in many respects. Without high quality customer metering no effective NRW management can take place.
- The quality of pipe construction and repairs as well as the quality of service connections in AAWSA must be improved in order to limit Real Losses resulting from an increased System Input Volume. Establishing continuous water supplies and, correspondingly, improved pressure regimes is also essential in controlling Real Losses.
- The continuous updating of the network maps, hydraulic models and databases is essential.
- Cooperative works with other organization such telecommunication, Telecommunication, Road Authority and etc. Most of time in construction of utility service, main line and distribution line was broken and highly losses of water are occurred as I was observing during field data collect.
- Establishing of calling center. In order to get information immediately during leakage of water by different causes, establishing of information center is essential.

REFRENCES

AAWA California Nevada section. (2002). Water audit and leak detection guidebook.

AAWSA. (2006). Addis Ababa Water and Sewerage Authority, Draft Sectoral Development Program(June 2006).

AAWSA. (2012). Addis Ababa Water and Sewerage Authority a brief profile. Addis Ababa, Ethiophia.

AAWSA. (2017). Addis Ababa Water and Sewerage Authority Akaki Branch Office Water Distribution Network Update:(August,2017).

Amdework B. (2012). Hydraulic Network Modeling and Upgrading of Legadadi Subsystem Water Supply(Case Study of Addis Ababa).

AWWA M36 Publication Rewrite (20014). Water audits and loss control programs. USA, America.

Bentley Water CAD/GEMs. (2008). Bentley Water CAD/GEMs “Water Distribution Design and Modeling,.

Central Statistical Agency of Ethiopia (2007). Summary and Statistical Report of the 2007.Population and Housing Census, Population size by Age and Sex, Addis Ababa,Ethiopia, United Nations Population Fund. Addis Ababa, Ethiopia.

Farley M. and Trow,S. (2003). Loss in Water Distribution Networks:A Practitioner's Guide to Assessment, Monitoring and Control.

Jeffrey A. Gilbert, P.E. (2009). Practical Design of Water Distribution Systems.

Kanakoudis V., Tsitsifli, S., Samaras, P., Zouboulis, A. & Demetriou, G. (2011). Developing appropriate performance indicators for urban water distribution systems evaluation at Mediterranean countries. Water Utility, 31-40.

Kimey V. (2008). Assessment of the Performance of Urban Water Supply Utilities: A case study of Korogwe and Muheza towns, Tanzania. MSc Thesis. University of Zimbabwe, Harare.

Lambert A. (2004). Practical Experience in using the infrastructure leakage index .

Lambert A.and Wallace,E. (2009). Accounting for losses-the “bust” and background concepts The Institution of water and Environment management symposium on leakage control in water industry.

Lambert A.O and. Mekenzie, R.D. (2008). Practical experience in using the infrastructure leak.

Larry W., M. (2004). Urban Water Supply Hand Book.

Liemberger R., Marin,P. (2006). The challenge of reducing nor -revenue water (NRW) in developing countries.

Malcolm F. (2008). Non-Revenue Water Handbook.

Mckenzie R., W. (2013). Lekage reduction through Pressure management in South Africa.

Melaku A. (2015). Assessement of Water Loss in Water Supply Networks in case of Debre Markos.

Ministry of Water Resources of Ethiopia (2012). Cost Effective Design Guidelines for Urban Water Supply Ministry of Water Resources of Ethiopia.

Mitchell,.V.G,R.G.,M.and T.A.M. (2009). Modeling the urban water cycle.

National Meteorological Agency of Ethiopia (2016). Climate of Addis Ababa,Ethiophia.

Pearson D. , T. (2005). Leakage Conference Proceedings.

Ronnie M. (2010). Aqualite water balance software user guide version2.2 report 2010.

SEURECA. (2007). Water supply project III.

Shaher Hussni Abdul Razaq Zyroud. (2003). Hdrualic Performance of Palastinian Water Distribution Systems.

Shimeles K. (2011). Water Supply Coverage and Water Loss in Distribution System with Modeling (Case Study of Addis Ababa).

Swamee, Prabhata K. (2014). Design of water supply pipe networks/Prabhata K. Swamee, Ashok K. Sharma.

Tahal Consulting Engineering. (2013). Addis Ababa Water Supply Project III A (AAWSP-III A).

Thomas M. W. (2009). Advanced water distribution modeling and management 2nd edition.

Twort A.C., Raw F.M., Crowley F.M. and Ratnayaka D.D. (2004). Water Supply Engineering.

UN Habital. (2003). Slums of the world :The faces of urban poverty in the new millennimum.

UNEP. (2007). Malta Water Service Corporation ,Leakage Control and Unaccounted For Water Analysis.

Wallingford., H. (2003). Handbook for assessmentof catchment water demand and use.

Welday, B. D. (2005). Water Supply Coverage and Water Loss in Distribution Systems, Addis Ababa.

WHO. (2000). Global Water Supply and Sanitation assessment 2000 report.

World Health Orginazation. (2011). Guidelines for Drinking-water Quality, 4th edition, . Geneva,Switzerland, WHO press.

APPENDIX

Appendix A: Checklist for discussion with local experts

No	Checklist for discussion with local experts
1	What are the main sources of water in the city? Are there any water sources that are not included to the distribution system? Where and how much?
2	Is there any difference in level of water distribution among different localities? If yes, how do you manage to balance the supply?
3	Is there any seasonal difference in amount (volume) of water supplied particularly in rainy season and dry season? If yes to what extent?
4	Are there any non-metered water consumptions? If so for what purpose and how do you estimate the volume of water consumed?
5	How do you estimate the residential water demand? Do you have any standard?
6	How do you identify leakage or breakage of water pipes? How do the residents/communities support in reporting leakage or breakage of pipes?
7	How frequent do water meters become defective? Do the customers report on time in case of defective water meter? If yes, do they report equally for both in case of the defect causing over readings and under readings? In case they didn't report how do you monitor it?
8	Have you encountered with illegal water connections? If yes how frequent? Do you think that all customers pay for all water they have consumed? If not why?
9	From your experience, does leakage and breakage of pipes have significant relation with age of pipes?
10	From your experience does the ground elevation difference of the city have a significant impact on pressure and distribution of water? How do you manage the pressure with the big elevation difference of the city?
11	Do you have a plan to replace aged pipes and water meters? What major criteria do you use for prioritization of replacement?
12	Do you have any plan regarding operation and management in general and leakage reduction in particular? If so what are the main components?

Appendix B: Population and Demand projection (2017-2037)

S.No	Year	population	un-served	Served	House	Yard	Yard shared	Public tab	Domestic	Non domestic	Una
0	2007	181270	4532	176738	1234517	1614503.91	1219493.93	903132.46	4971646.9725	1740076.44	1
1	2008	188857	4721	184135	1286184	1682074.30	1270532.31	940930.45	5179720.87	1812902.30	1
2	2009	196761	4919	191842	1340013	1752472.65	1323706.77	980310.37	5396503.09	1888776.08	1
3	2010	204995	5125	199871	1396096	1825817.32	1379106.68	1021338.43	5622358.11	1967825.34	1
4	2011	210185	4204	205981	1724063	2248284.85	1745690.71	889838.80	6607877.05	1982363.11	2
5	2012	218107	4362	213745	1789048	2333029.50	1811491.07	923379.52	6856947.89	2057084.37	2
6	2013	226329	4527	221802	1856482	2420968.43	1879771.64	958184.48	7115406.97	2134622.09	2
7	2014	234860	4697	230162	1926459	2512222.04	1950625.91	994301.35	7383608.16	2215082.45	2
8	2015	243712	4874	238838	1999073	2606915.28	2024150.89	1031779.57	7661918.65	2298575.60	2
9	2016	246161	3692	242469	2461788	3158401.60	3243023.29	193975.22	9057188.181	2717156.454	26
10	2017	254675	3820	250855	2546928	3267633.67	3355181.97	200683.78	9370427.472	2811128.242	27
11	2018	263483	3952	259530	2635013	3380643.50	3471219.62	207624.35	9694500.02	2908350.006	28
12	2019	272595	4089	268506	2726143	3497561.73	3591270.39	214804.96	10029780.49	3008934.148	29
13	2020	282023	4230	277792	2820426	3618523.52	3715473.06	222233.90	10376656.51	3112996.952	3
14	2021	283720	2837	280883	3415534	4364636.94	3830117.08	238750.33	11849038.50	3554711.551	32
15	2022	292946	2929	290016	3526599	4506564.04	3878968.665	246513.90	12158645.41	3647593.622	33
16	2023	302472	3025	299447	3641275	4653106.26	4005103.05	254529.91	12554014.22	3766204.267	34
17	2024	312307	3123	309184	3759680	4804413.67	4135339.009	262806.59	12962239.45	3888671.835	35
18	2025	322463	3225	319238	3881936	4960641.22	4269809.917	271352.41	13383739.14	4015121.742	36

19	2026	326682	1633	325049	4496074	5717282.00	4432364.399	276291.42	14922011.77	4476603.53	40
20	2027	336968	1685	335283	4637635	5209963.26	4571919.625	284990.59	14704508.58	4411352.574	39
21	2028	347577	1738	345840	4783653	5374001.58	4715868.818	293963.66	15167487.44	4550246.233	40
22	2029	358521	1793	356729	4934269	5543204.73	4864350.324	303219.26	15645043.43	4693513.028	42
23	2030	369809	1849	367960	5089627	5717735.32	5017506.845	312766.27	16137635.50	4841290.651	4
24	2031	365325	1827	363498	5469925	6393574.61	4335809.762	308973.70	16508283.06	4952484.918	43
25	2032	376150	1881	374269	5632002	6583019.42	4464281.973	318128.75	16997431.74	5099229.522	44
26	2033	387295	1936	385359	5798881	6778077.58	4596560.88	327555.06	17501074.14	5250322.243	4
27	2034	398771	1994	396777	5970704	6978915.40	4732759.277	337260.68	18019639.72	5405891.916	47
28	2035	410587	2053	408534	6147619	7185704.16	4872993.301	347253.88	18553570.65	5566071.196	48
29	2036	411862	2059	409802	6665026	8014505.52	4888123.019	348332.04	19915986.80	5974796.041	48
30	2037	423684	2118	421565	6856341	8244555.89	5382547.916	358330.65	20841775.25	6252532.575	51

Appendix C: Customer Billed Data of Akaki branch (2015-2017)

Appendix C1: Customer Billed Data for 2015

Month	Domestic	Non Domestic	Fountain	Total Consumption	No of Customers
January	174029	315162	8789	497980	25332
February	185251	286728	12436	484415	26227
March	198764	271668	11350	481782	27108
April	178491	286295	8766	473552	27110
May	178116	694668	8947	881731	27496
June	175180	275860	8186	459226	27881
July	171869	265424	7607	444900	28265
August	162101	240339	7351	409791	28242
September	224081	259669	8189	491939	28766
October	189268	219483	8523	417274	28992
November	212764	308340	11921	533025	29279
December	200056	280666	10219	490941	29493
Total	**2249970**	**3704302**	**112284**	**6066556**	

Appendix C2: Customer Billed Data for 2016

Month	Domestic	Non Domestic	Fountain	Total Consumption	No of Customers
January	225210	264458	9399	499067	29773
February	232743	278571	8357	519671	29823
March	272480	264411	13447	550338	30475
April	259213	330990	8165	598368	30479
May	228748	320896	8214	557858	30816
June	198283	310801	8264	517348	31152
July	199518	310531	8054	518103	31831
August	227879	272337	5572	505788	32618
September	288243	348757	8168	645168	33774
October	232908	361095	14873	608876	35663
November	258857	305840	8802	573499	37392
December	245741	319989	8026	573756	38531
Total	**2869823**	**3688676**	**109341**	**6667840**	

Appendix C3: Customer Billed Data for 2017

Month	Domestic	Non Domestic	Fountain	Total Consumption	No of Customers
January	267839	297918	11249	577006	39349
February	269465	272155	7353	548973	40208
March	299700	289966	6849	596515	41615
April	299271	282554	9350	591175	41986
May	309165	319026	7602	635793	43268
June	298572	279340	8367	586279	43465
July	287978	284272	9132	581382	43662
August	266092	264381	6800	537273	43747
September	299962	249100	7669	556731	44100
October	331958	330273	7194	669425	44774
November	317586	399112	6978	723676	46006
December	313776	375772	6356	695904	46645
Total	**3561364**	**3643869**	**94899**	**7300132**	

Appendix C4: Total Billed Consumption (2015-2017)

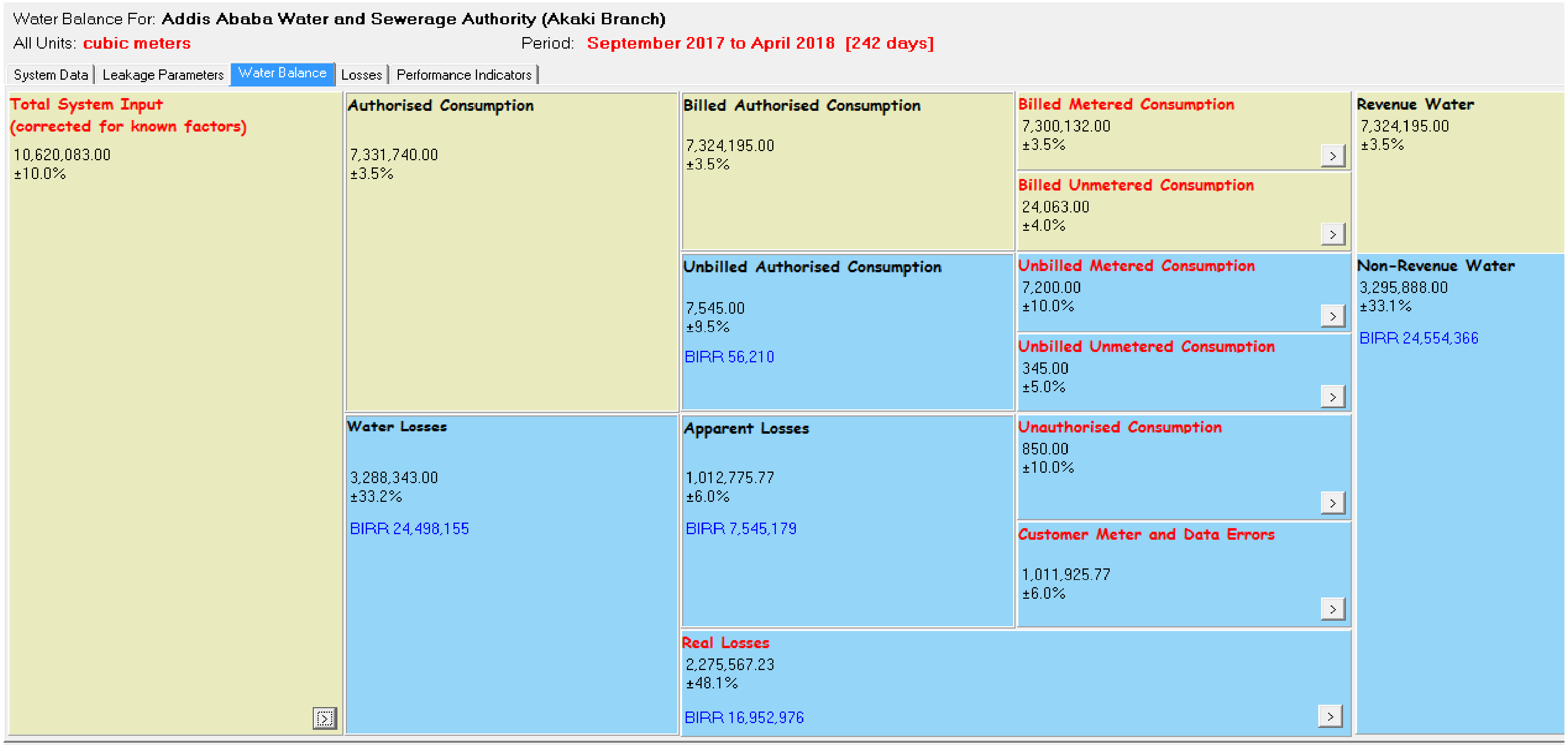
Year	Production (m^3/year)	Total Billed Data /Consumption(m^3/year)				Total Population	Consumption L/person/day
		Domestic	Non-domestic	By Trunk	Total		
2015	9982378.69	2362254	3704302	22695	6089251	243712	26.56
2016	10615825.40	2979164	3688676	20130	6687970	262169	31.13
2017	11436198.44	3561364	3643869	19035	7319167	273141	35.72

Appendix D: Result Summery of the Five Pilot DMA

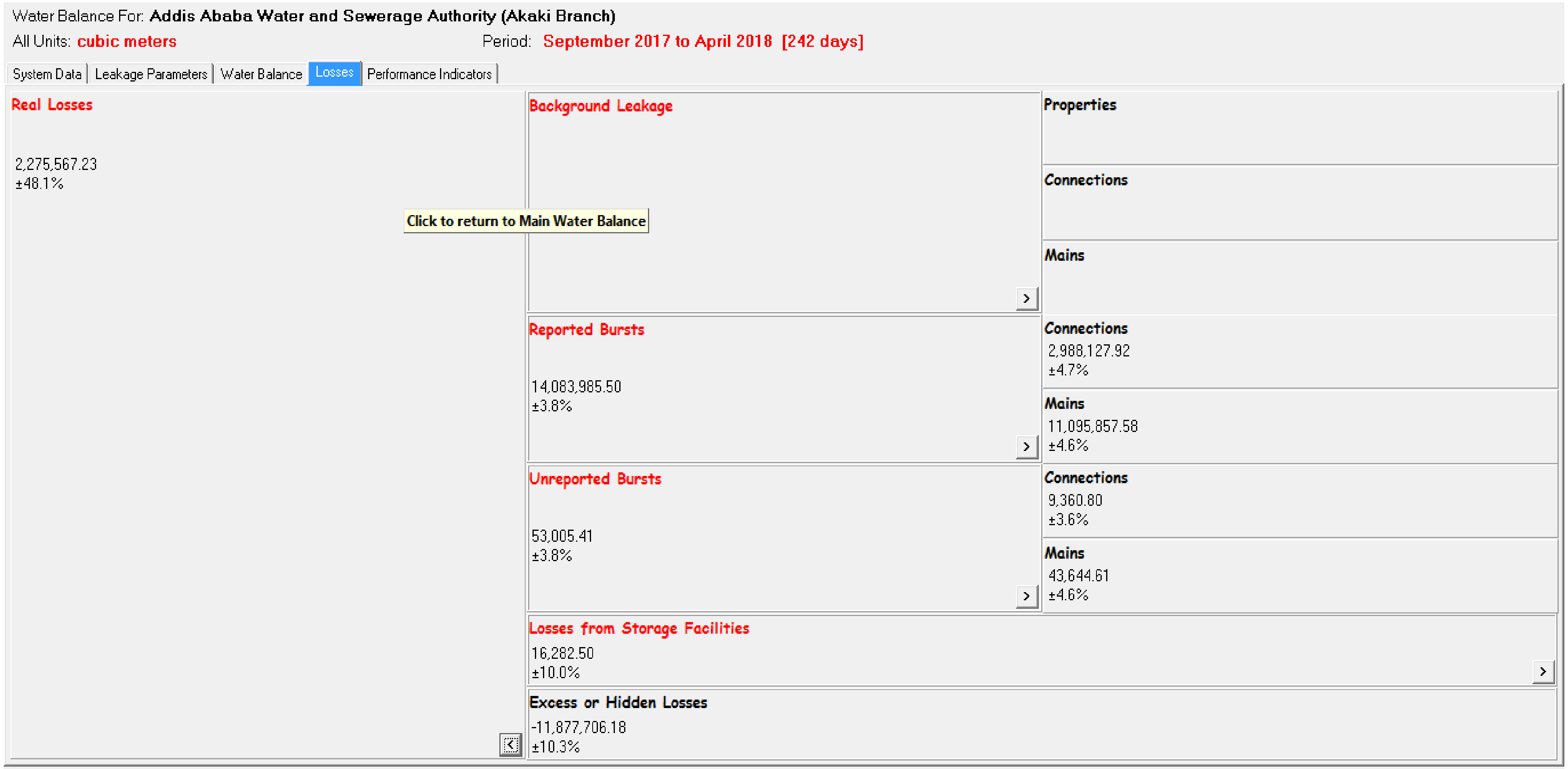
S.No	DMA	Location	Coverage area (sq.km)	Customer size			C distr P leng
				Domestic	Non Domestic	Public Tap	
1	DMA-1	Salo gora	0.36	669	96	0	6
2	DMA-2	woreda 8 around KK textile factory	0.32	293	50	0	3
3	DMA-3	Woreda 8 CBE Melka Shane Branch	0.3	505	60	2	3
4	DMA-4	wereda 7 around cheralia condominium	0.29	526	142	0	5
5	DMA-5	Akaki town	0.52	1241	236	11	7
SUM			1.79	3234	584	13	2

Appendix E: Aqua lite Water balance Software

Appendix E1: Water balance Result



Appendix E2: Water Losses Result



Appendix E3: Calculation of Performance Indicators

Water Balance For: **Addis Ababa Water and Sewerage Authority (Akaki Branch)**

All Units: **cubic meters** Period: **September 2017 to April 2018 [242 days]**

System Data | Leakage Parameters | Water Balance | Losses | Performance Indicators

Base data used in calculations

		Value	Error %	Lower	Upper
Average pipe length from street edge to meter	meters	3.00	5	2.9	3.2
Length of trunk mains	kilometers	684.6	10.0	616	753
Length of distribution mains	kilometers	2,061.4	10.0	1,855	2,268
No. of service connections		46,648	10.0	41,983	51,313
Connection density (distribution)	connections/km	22.63	14.1	19.43	25.83

		Value	Error %	Lower	Upper
Average system pressure	meters	35.71	10	32.1	39.3
Average trunk pressure	meters	60.00	10	54.0	66.0
Percentage time pressurised - system		67.34	10	60.6	74.1
Percentage time pressurised - trunk mains		90	10	81.0	99.0
Number of accounts		209,916	10.0	188,924	230,908

Unavoidable annual real losses

	m3/day	Error %
On Trunk Mains	665	17.3
On Distribution Mains	892	11.0
On service connections to street boundary	897	14.5
On service connection from street edge to meter	84	15.3
Total unavoidable real losses	2,538	15.3

Cost Factors

Monetary Unit		BIRR
Real loss cost	BIRR/m3	7.4500
Apparent loss cost	BIRR/m3	7.4500
Cost of running the system	BIRR	

Performance Indicators

		Best Estimate	Lowest Estimate	Highest Estimate		Best Estimate	Lowest Estimate	Highest Estimate
Non Revenue Water Basic (IWA Level 1, Fi37)	% of System Input By Volume	31.0	20.3	41.8				
Apparent Losses	l/account/day	29.6	27.8	31.4				
Real Losses Basic (IWA level 1, Op24)	l/connection/day when pressurised	299.3	149.3	449.4	l/km mains/day	6,773.9	3,377.7	10,170.1
Real Losses Intermediate	l/connection/day/m pressure when pressurised	8.4	4.1	12.7	l/km mains/day/m pressure	189.7	92.7	286.7
Non Revenue Water Basic (IWA Level 1, Fi38)	% of System Input By Value							
Real Losses Detailed (IWA Level 3, Op25)	Infrastructure Leakage Index	3.70	1.83	5.58				

Appendix F: Photos of equipments used to collect data

Appendix F1: Pressure Logger


Appendix F2: Correlator, SeCorr 08

Appendix F3: Ground microphone, Aquaphon A100

Appendix F4: Pipe locator, UT 830

Appendix F5: Small listening stick, Stethophon 04